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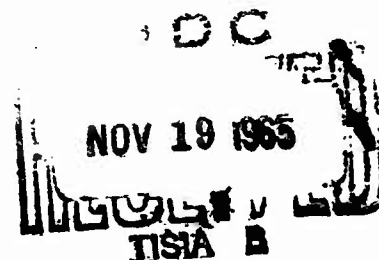
**SHOCK CHARACTERISTICS OF SMALL PENTOLITE CHARGES
DETONATED IN VESSELS HYDROSTATICALLY PRESSURED
FROM AMBIENT TO 4000 PSI**

B. W. Vanzant
R. C. DeHart

Final Report
Contract No. Nonr-3940(00)
Project 03-1284

Prepared for

Department of the Navy
Office of Naval Research
Field Project Branch
Washington 25, D. C.



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September 7, 1965

SOUTHWEST RESEARCH INSTITUTE
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ABSTRACT

Underwater explosions at great depth have been simulated by detonating small spherical pentolite charges in vessels hydrostatically pressured to 4000 psi. An increase in hydrostatic pressure is found to have no effect on the peak magnitude of the primary shock wave, but the impulse per unit area and the duration of the positive phase of the initial pressure pulse are observed to decrease with an increase in hydrostatic pressure. The magnitude of the negative phase of the shock wave increases as the hydrostatic pressure increases. Although little difficulty is encountered in studying primary pressure pulses in pressure vessels, secondary pressure pulses created by expansion and contraction of the gas bubble formed by the detonation are difficult to observe due to the large displacement of the water particles at close-in distances and the associated acceleration of the piezoelectric pressure transducer at the times of interest. Also, the myriad of reflections from the gauge positioning devices and the vessel walls and the inconsistency usually exhibited by bubble pulses under seemingly identical conditions complicate analysis of the secondary pulses. The magnitude of the bubble pulse appears to increase as the hydrostatic pressure increases, and, at moderately high hydrostatic levels, the frequency of the bubble oscillation is such that the bubble pulse is recorded as a vibration.

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I. INTRODUCTION

In full-scale ocean tests, pressure measurements close to the detonation center of deep explosions are both expensive and technically difficult. Consequently, theoretical studies^(1, 2) of underwater explosions at great depths have been based on pressure recordings taken at relatively long distances from the center of the explosion but conveniently close to the surface. The use of pressure vessels to study shock waves from charges detonated under high hydrostatic pressure has facilitated observations of the pressure pulses at close-in distances.

The measurement of the initial shock pressures from a detonation contained within a pressure vessel is rather straightforward. Secondary pressure surges, such as the pulses created by the swelling and contraction of the gas bubble formed by the detonation, are difficult to observe, however, due to reflections within the vessel. This report is concerned with summarizing measurements of the characteristics of the primary shock wave under increasing hydrostatic pressures, summarizing observations of the effect of hydrostatic pressure on the bubble pulse at close-in distances and discussing the utility and difficulties associated with the use of pressure vessels for studying the effects of underwater explosions superposed on high hydrostatic pressures.

II. SUMMARY AND CONCLUSIONS

Primary pressure pulses from small charges are readily observed in vessels hydrostatically pressured to 4000 to 5000 psi. It is expedient that the vessel diameter be large enough to prevent reflection from the walls prior to the end of the pulse. Some difficulty is encountered with small, eight-gram charges in that observed values more often deviate from anticipated or calculated values than do 13-gram charges. This is perhaps due to the fact that the blasting cap used to initiate detonation is a greater percentage of the charge weight and the pressures it generates are more directional than the main spherical charge. With both size charges, however, it is observed that hydrostatic pressure does not alter the peak pressure of the initial shock wave. It is further noted that both the duration and impulse per unit area of the positive pressure phase decrease with an increase in hydrostatic pressure. The magnitude of the negative phase of the initial pressure pulse increases as the hydrostatic pressure increases.

Bubble pulses from small charges are difficult to produce with any degree of consistency. Measurement of their characteristics in a pressure vessel is impeded by vibration and reflection, and it is necessary to compare peak to peak pressure values from bubble pulses at high hydrostatic pressures. The bubble pulse period agrees rather well with the predicted value for all levels of hydrostatic pressure to 3000 psi. At

the higher pressures (even 500 psi), the bubble pulses appear as a continuous damped vibration, which is the reason for the peak to peak comparison. This peak to peak value increases as the hydrostatic pressure increases.

The apparent limitation of pressure vessels for studying secondary pulses from underwater explosions at great depth may be overcome with a technique for damping reflection at the vessel walls. Appropriate wire mesh adjacent to the wall may not only dissipate the impinging shock and prevent reflection but may also afford some protection to the vessel. A method for bubbling air adjacent to the wall prevents shock reflection, but it also disturbs the primary pulse at the point of interest. It is recommended that this method be investigated further to provide greater utility in the use of pressure vessels for studying secondary pulses at distances close to the detonation center.

III. DESCRIPTION OF FACILITY AND INSTRUMENTATION

Testing was accomplished in two pressure vessels, one with a two and one-half-foot inside diameter and the other with a four-foot inside diameter. The 30-inch vessel was used primarily for studies of the initial shock pulse while the four-foot vessel was utilized for observations of the bubble pulse.

Spherical pentolite charges cast by Naval Ordnance Laboratories, White Oak, Silver Spring, Maryland were used in all of the tests. All charges had a cap well and detonation was initiated with Hercules J-2 Engineers Special EB caps, which have a pentolite equivalent of 1.1 gms. The 13.5-gm charges had a diameter of one inch, and the 7.5-gm charges had a diameter of five-sixths inch. Plastic pipe with a plastic steel filler was used to reinforce the blasting cap for high pressure shots, as shown schematically in Figure 1. The reinforcing was used in all shots to insure consistency in charge configuration for all shots. It was necessary to immerse the pentolite charge about one-sixteenth inch into the plastic steel filler to obtain detonation at pressures above 2,500 - 3,000 psi. This immersion was not necessary for the low pressure shots.

Pressures were measured with 1/4" diameter tourmaline piezo-electric crystals manufactured and calibrated by Crystal Research, Inc., Cambridge, Massachusetts. Voltages generated by these gages were

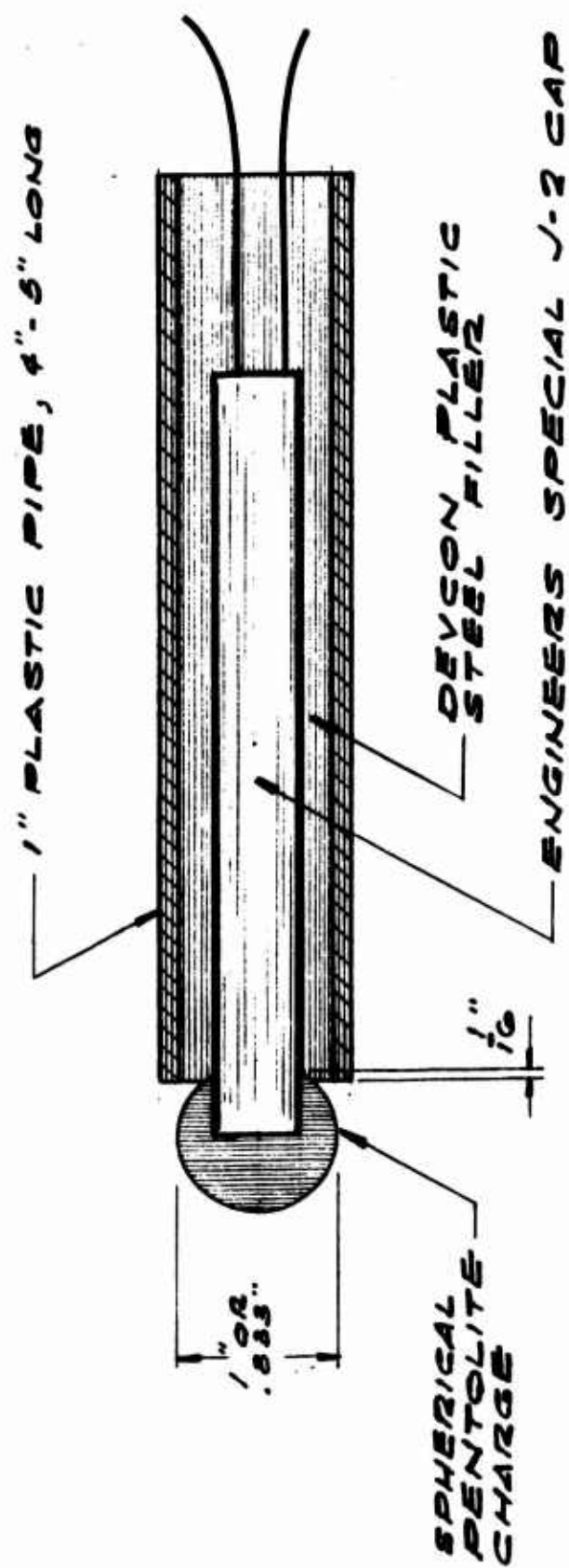


FIGURE 1. SCHEMATIC OF CHARGE ASSEMBLY

transmitted from the pressure vessel by an uninterrupted length of one-half-inch diameter low noise coaxial cable. (Specifically, the cables were Simplex Antimicrophonic Cable, two conductors No. 18 AWG.)

A continuous cable through the pressure vessel wall was deemed desirable to prevent an added problem of electrically insulating a connector at a high pressure seal. Several types of seals were investigated, all of which operated successfully to around 1000 psi. An O-ring type seal allowed the cable to be extruded with no visible damage after a couple of shots at 1000 psi. A wedge type teflon seal appeared to be satisfactory to about 2000 psi, but with an increase in pressure it was necessary to tighten the wedge to a point where the twinex leads were parted. It was also determined that an appropriate wedge could not be vulcanized as an integral part of the cable without extreme difficulty.

(3)
A suitable seal, as shown in Figure 2, was finally obtained by using Devcon plastic steel diluted with a softening agent. When a thinner was used to insure complete penetration to thin parts of the wedge, adequate stiffness and strength were not achieved. The desired flexibility of the filler approximated that of a rubber tire.

To achieve proper bonding between the neoprene surface of the cable and the plastic filler, it was necessary to roughen the neoprene with sandpaper and clean it with toluene. The seal assembly operates on the principal of pressure induced friction, and it is important to insure slight

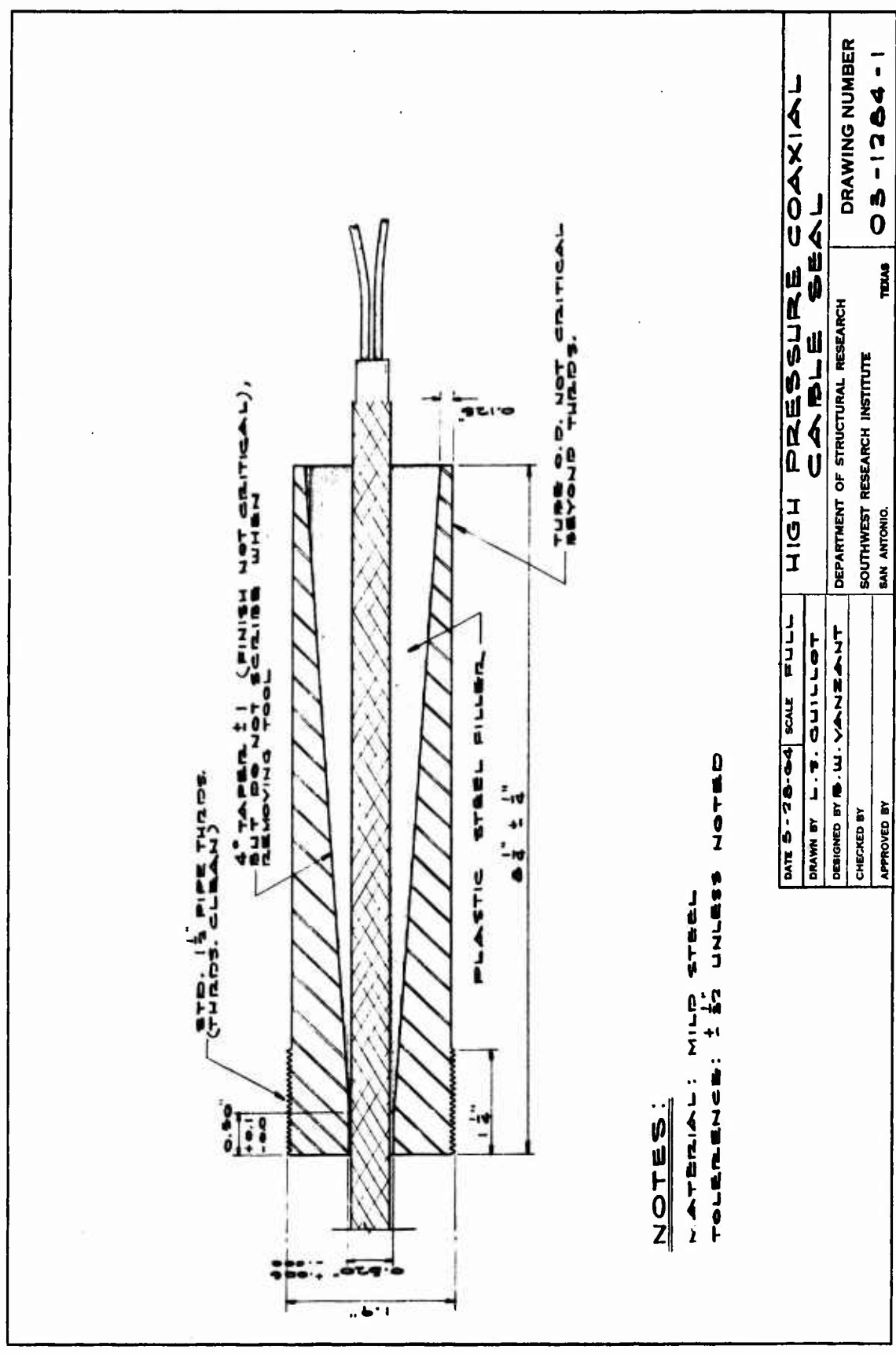


FIGURE 2. HIGH PRESSURE COAXIAL CABLE SEAL

flexibility of the plastic filler to prevent relative motion between various layers of the coaxial cable. There should not, however, be relative motion between the Devcon filler and the steel housing.

Calibrating capacitors of .01 microfarads were placed in parallel with the piezoelectric crystals at the terminus of the low noise simplex cable. This capacitance was large relative to the transducer and cable capacitance (of around 0.0007 microfarads) and minimized any effect of impinging shock on the cable capacitance and its consequent effect on the transmitted signal.

Signals from the tourmaline transducers were displayed on Tektronix 502 oscilloscopes. The differential amplifiers internal to the scopes were used on all tests after the initial three shots. Displays were recorded on Polaroid Type 37 film through the use of a Dumont Type 302 Oscillograph Record Camera with an f/1.9 lens.

The oscilloscopes were triggered with a breakwire activating the single pulse circuit shown in Figure 3. This device was successful in limiting the scopes to a single sweep. It also served as a calibration unit for scope deflection by generating a one-volt instantaneous step with a 30-microsecond decay.

A 100-KC marker generator (Figure 4) was used as a timing calibrator in several shots through the use of the Z-axis of the oscilloscopes. Every ten microseconds, the accelerating potential of the electron beam

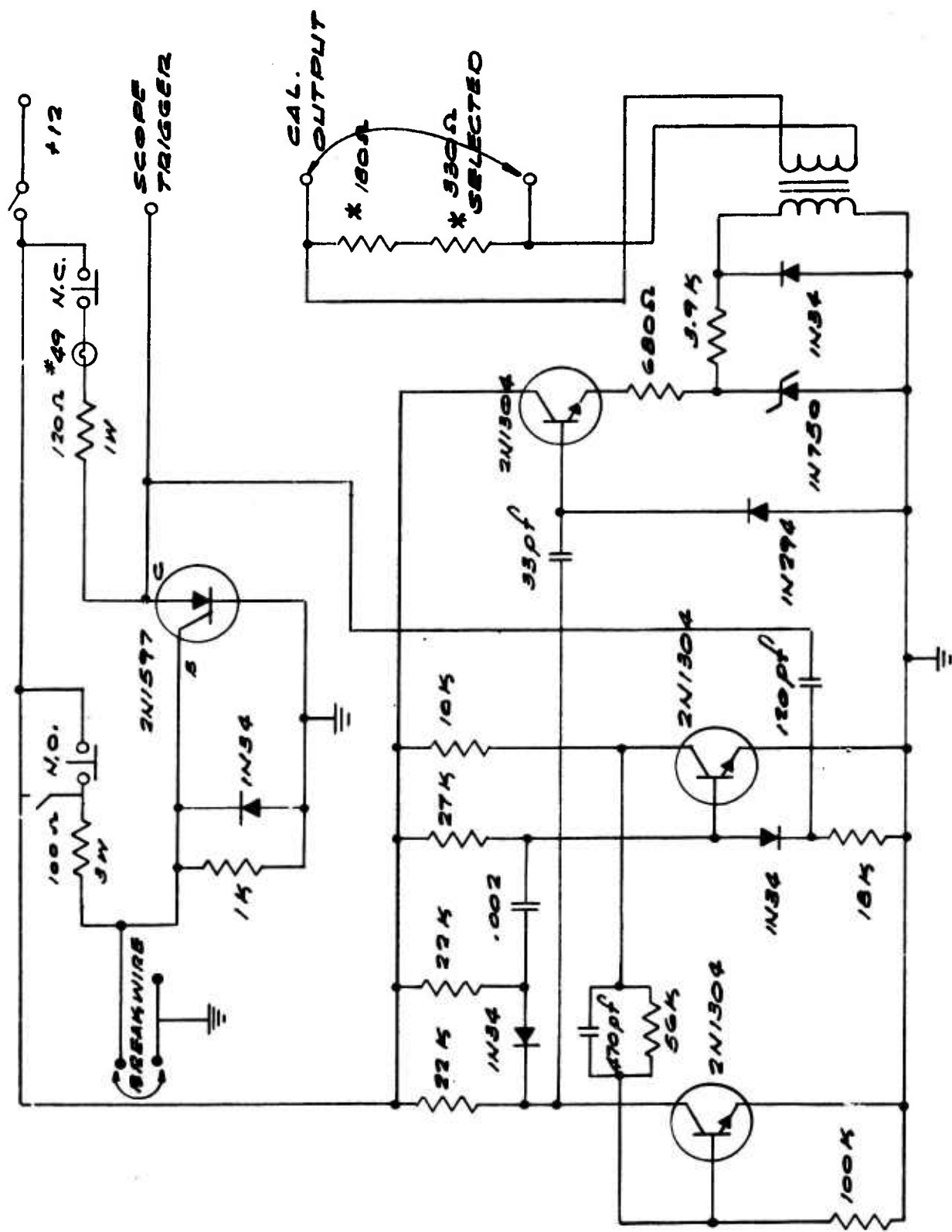


FIGURE 3. CALIBRATION PULSE GENERATOR AND TRIGGER LOCKOUT

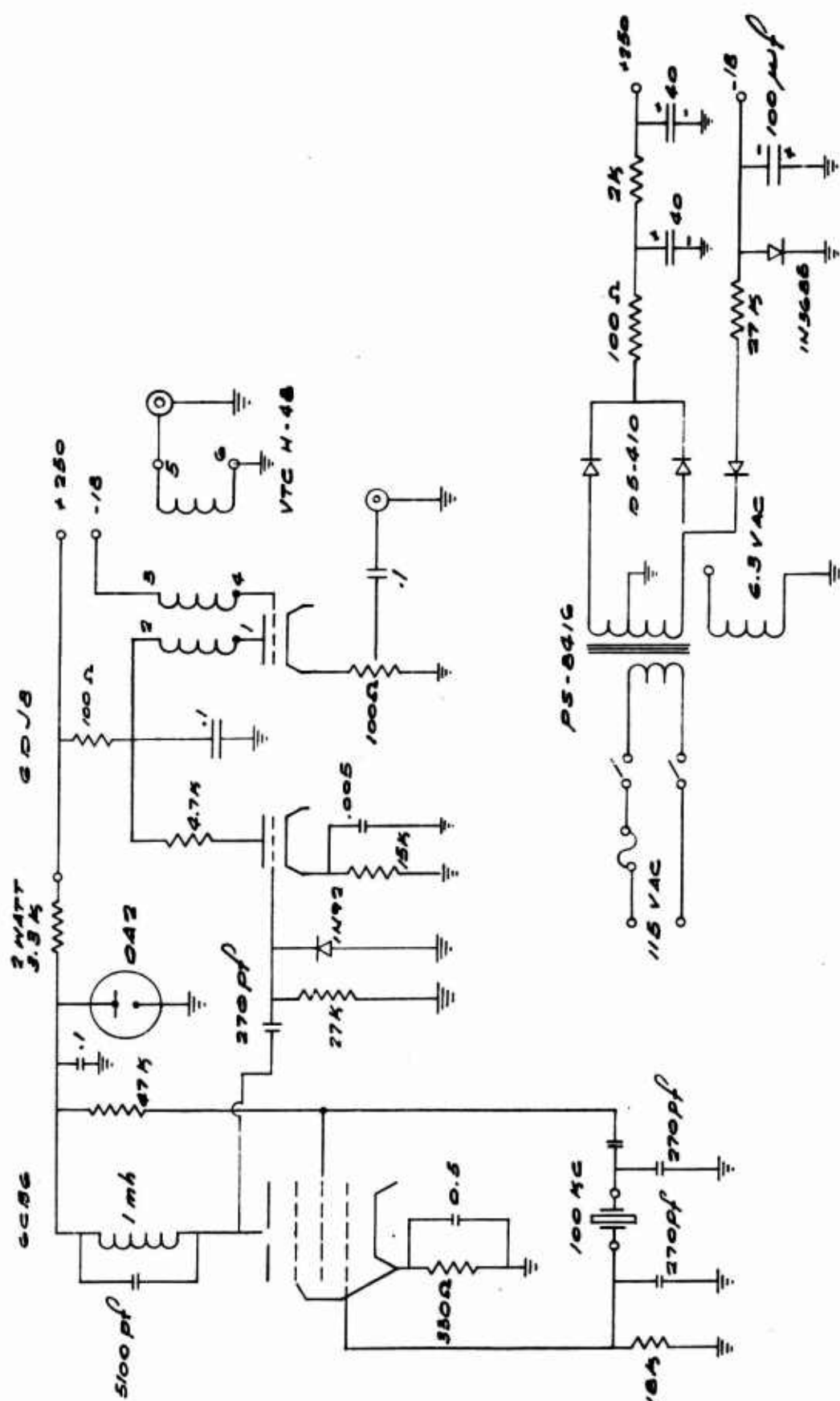


FIGURE 4. 100-KC MARKER GENERATOR

was turned off. This method was abandoned, however, since it interfered with the clarity of the recorded trace.

IV. MEASUREMENT OF SHOCK WAVE CHARACTERISTICS

The pressure-voltage relation for tourmaline gauges is given by

$$p = \frac{c}{ka} v \quad 1)$$

where

- p = pressure, psi
- c = capacitance, farads
- ka = gauge constant, coulombs/psi
- v = scope deflection, volts

An empirical relation from which the peak overpressure can be predicted is⁽⁴⁾

$$P_c = k \left(\frac{w^{1/3}}{R} \right)^\alpha$$

where

- P_c = calculated peak overpressure, psi
- w = charge weight, lbs.
- R = distance from charge, ft.
- k, α = empirical constant

For the spherical 50/50 pentolite charges used in these tests, $k = 22,500$, $\alpha = 1.13$. The J-2 caps used as initiators were equivalent to 1.1 gms of pentolite.

In the initial tests in the 30-inch tank, the gage-charge suspension assembly was such that an early reflection from the gauge mount was

possible. Results of the first three tests, during which an external amplifier was used, are shown in Appendix A (Figures 1A, 2A, and 3A). Even though drift in the amplifier precluded accurate calibration, peak overpressures at static pressures of zero and 500 psi are seen to be equivalent. It is to be noted that area measurements for unit impulse were not always possible in the initial shots. After the first three shots, the oscilloscope differential amplifiers were used to magnify the tourmaline response. Data from Shots 7 through 10 are shown in Figures 4A through 7A.

Prior to Shot 12, the suspension assembly was modified as shown in Figure 5 so that the gages could be positioned with tape on small wires to alleviate the problem of early reflection. Also, epoxy seals⁽³⁾ were implemented for the first time. In order to avoid systematic increase or decrease in hydrostatic pressure and any associated drift in tourmaline response due to such a procedure, a pressure of 3500 psi was randomly chosen for Shot 12. At 2900 psi, however, the seal on Gauge 527 could not contain the pressure. The pressure had leaked to around 1540 psi before the charge could be detonated. At around 800 psi, the seal again functioned properly. From Figure 8A, it is seen that pressures were higher than anticipated at three locations. Shot 13 (Figure 9A) was made at zero pressure for purposes of calibration. Again the measured pressures exceeded calculated values. Another attempt was made to shoot in a 3500-psi medium, but at 3200 psi the firing line broke. The seal on Gauge 527

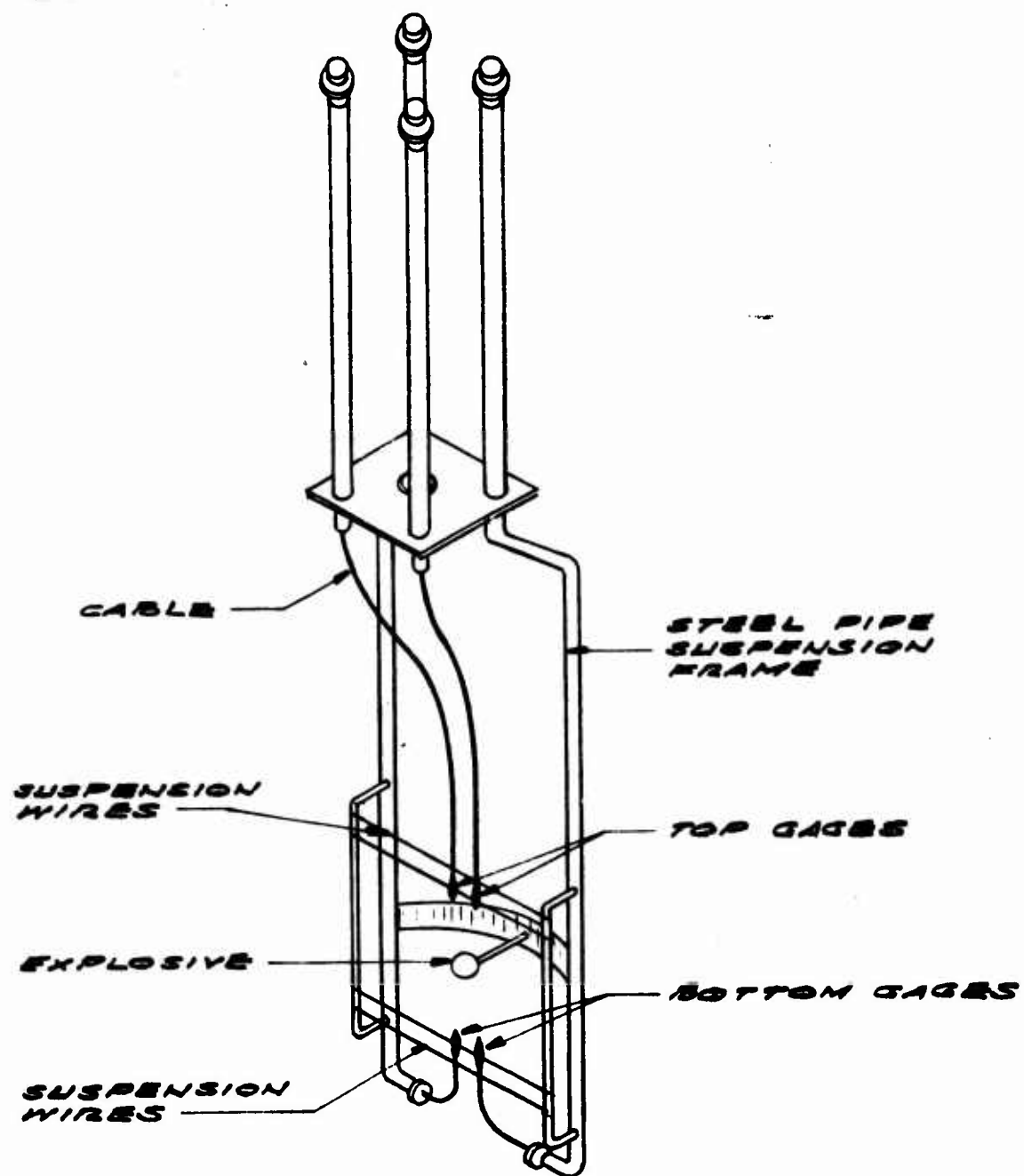


FIGURE 5. SCHEMATIC OF SUSPENSION
FRAME

failed at 2700 psi upon repressurization. Shot 14 was finally accomplished at 2000 psi, after the lead-through to Gauge 527 had been blanked. Figure 10A shows that the response again was high.

It was noted that the high pressures in Shots 12 through 14 corresponded to pressures that should be obtained one-half inch closer to the charge. Distances were predicated on the basis of length from center of charge to gauge tip, and errors in measurement were probably less than one-eighth inch. Also the consistency of above average pressures in corresponding to distances a charge radius closer to the gauge indicated that spatial configuration was probably at fault. That is, the alignment of the gauges relative to the charge was such that the gauges were on (or nearly on) the blasting cap side of the charge. The rod holding the charge was shortened so that the gauges would be on the side of the charge away from the cap. This introduced the difficulty of aligning the gauges to point straight at the charge. Shot 15 (Figure 11A) was accomplished at 3000 psi, but a higher than anticipated pressure was measured at one of the positions. Again the positioning device for the charge was shortened. The charge was detonated at 1500 psi for Shot 16 (Figure 12A), during which a timing mark was superposed on the recorded signal. Unfortunately, the peak response could be distinguished only when the original recording was placed on a light table.

Shots 17 and 18 (Figures 13A and 14A) were calibration shots at zero pressure. Shot 19 (Figure 15A) was made at 3500 psi. Gauge 529 was

replaced after it leaked at low pressure. Unfortunately, the seal on the gauge used to replace Gauge 528 extruded prior to detonation.

In Shot 20 (Figure 16A), the cable seals successfully contained 4500 psi, even after detonation. The spherical pentolite charge did not detonate, however, as evidenced by both explosion noise and charge fragments remaining in the vessel.

Shot No. 21 (Figure 17A) was a calibration shot at ambient pressure. Prior to Shot 22 (Figure 18A) a leak developed in one of the cable seals, and the eight-inch air blanket normally maintained at the top of the pressure vessel for each shot was lost; but a pressure of 1,000 psi was achieved with little difficulty and the charge was detonated. The lack of an air blanket did not appear to affect the characteristics of the shock wave, however.

Shot 23 was made at 500 psi (Figure 19A). In Shots 24 and 25, the electric blasting caps failed at 2400 and 2800 psi. Shot 26 (Figure 20A) was a calibration shot, and Shot 27 (Figure 21A) was made under a hydrostatic pressure of 4000 psi. During a subsequent attempt to shoot at 4500 psi, the blasting cap failed at 3950 psi.

Peak pressures achieved from detonation of the 13.7-gm charges are shown in Table I. In Figure 6, the ratio of the peak measured pressure, P_p , to the peak calculated pressure, P_c , is plotted against hydrostatic pressure. This ratio stays close to unity and indicates that an increase in hydrostatic pressure does not affect the magnitude of the peak

TABLE I

SUMMARY OF PEAK PRESSURES FOR 13.7-GM CHARGES

Ambient Press., psi	Shot No.	12"		8"		Comments
		TOP GAUGES Press., psi	Press., psi	BOTTOM GAUGES Press., psi	Press., psi	
Zero	1	7370 ¹	9040 ¹	8210 ²	-	External Amplifier Early Reflection
500	5	6550 ³	6640 ³	8490 ⁴	-	
500	6	7100 ⁵	7950 ⁵	8400 ⁶	11480 ⁶	
Zero	7	-	-	8820 ¹	9040 ¹	Early Reflection
Zero	8	6010	6080	9640	9860	
Zero	10	6050	6000	9700	9680	
1000	9	6120	6090	9640	10130	
Zero	13	6560	6440	10600	-	
Zero	17	-	6660	10350	9630	
Zero	18	6010	6240	9800	9900	
1500	12	6990	6810	9760	10700	
1500	16	6150	6100	9800	9620	
2000	14	6700	6680	-	10200	
3000	15	6000	6100	10900	9630	
3500	19	6290	6240	-	9900	
4500	20	1120	1130	1950	1920	Cap Only Detonated
Zero	21	-	6240	11215	9550	No Air Blanket
1000	22	6950	6400	10400	10100	
500	23	6190	6410	9860	9840	
Zero	26	6000	6400	10150	10050	
4000	27	6410	6250	10150	9840	

1. 8-3/4"

2. 9"

3. 11-1/4"

4. 8-5/8"

5. 10"

6. 8-1/4"

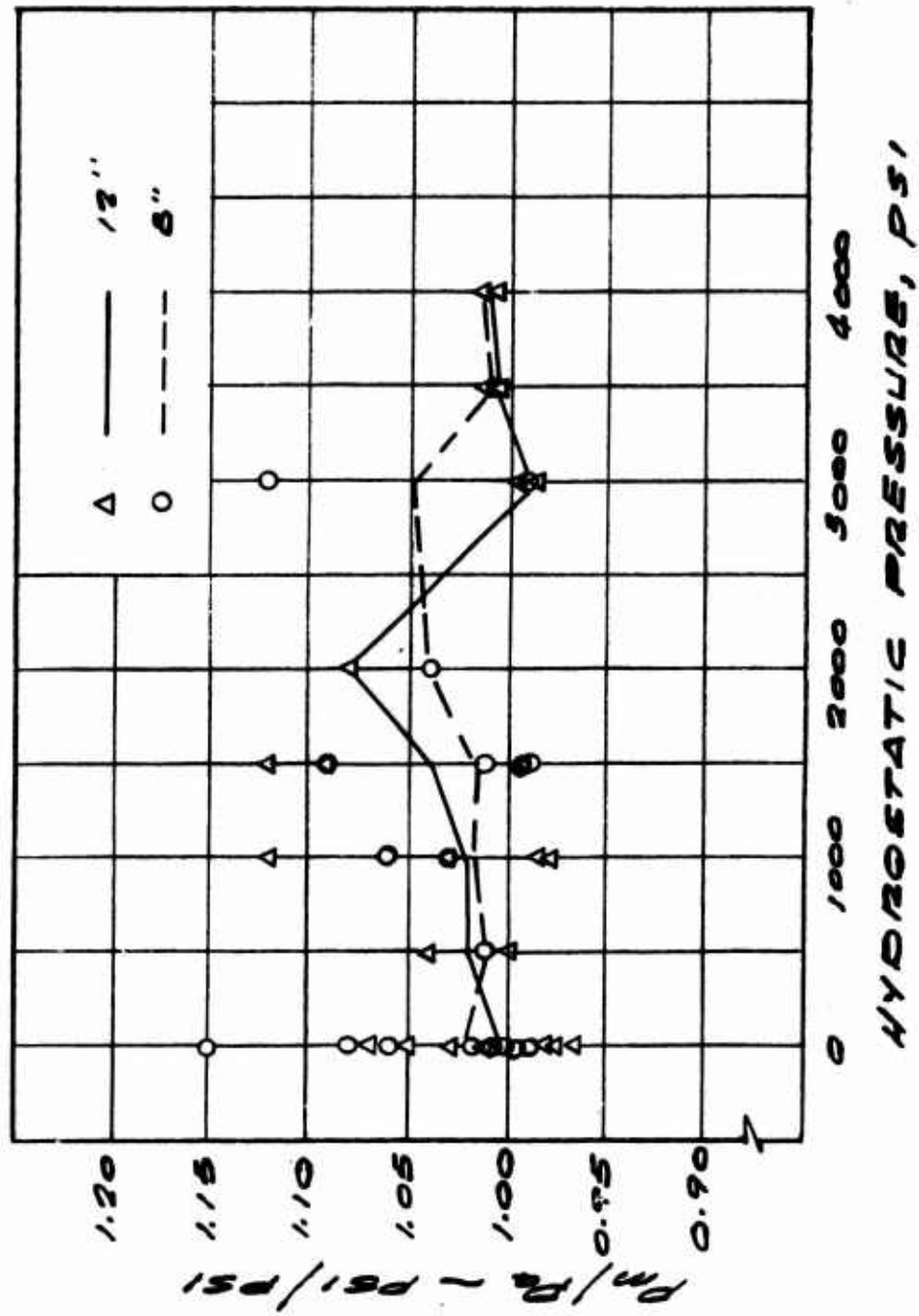


FIGURE 6. RATIO OF MEASURED TO CALCULATED PEAK OVERPRESSURE
FROM 14.7 TO 14.8-GM CHARGES OF PENTOLITE AT 8 INCHES
AND 12 INCHES VERSUS HYDROSTATIC PRESSURE

overpressure. The duration of the positive phase of the pressure pulse is summarized in Table II. For zero hydrostatic pressure, it was difficult to assess the time required for the shock pressure to return to zero, but, as shown in Figure 7, an increase in hydrostatic pressure definitely decreased the duration of the overpressure.

The area under the positive pressure phase is equivalent to the impulse per unit area. A summary of these measurements is shown in Table III and Figure 8, where it is seen that the impulse decreases as the hydrostatic pressure increases.

Table IV and Figure 9 show the magnitude by which the pressure pulse goes below the hydrostatic pressure. It is evident that the negative pressure (relative to the original hydrostatic pressure) increased as the hydrostatic pressure was increased.

It is sometimes convenient to use semi-log plots to compare the characteristics of shock waves. Representative curves for shock waves from 13.7-gm charges detonated at 1, 1500, 3000, 3500, and 4000 psi are shown in Figures 22A through 26A, respectively. These curves are summarized in Figure 10 for the pressure at 12 inches and in Figure 11 for the pressure at 8 inches. The summaries show that the slope of the decay is more rapid for the higher hydrostatic pressures.

TABLE II
SUMMARY OF PULSE DURATIONS FOR 13.7-GM CHARGES

Ambient Press., psi	Shot No.	12" TOP GAUGES			8" BOTTOM GAUGES			Comments
		Duration Sec.	Duration Sec.	Duration Sec.	Duration Sec.	Duration Sec.	Duration Sec.	
0	1	-	-	127	125	External Amplifier Early Reflection		
500	5	130	132	-	-			
500	6	130	130	112	122			
0	7	-	-	-	-	Early Reflection		
0	8	-	-	140	130			
0	10	-	-	-	-			
1000	9	125	125	122	115			
0	13	155	150	127	-			
0	17	-	162	127	127			
0	18	152	177	122	127			
1500	12	117	112	105	105			
1500	16	112	110	105	105			
2000	14	115	107	-	97			
3000	15	82	85	77	77			
3500	19	75	77	-	70			
0	21	160	162	127	130	No Air Blanket		
0	26	155	165	140	130			
500	23	140	135	125	120			
1000	22	130	125	120	115	Cap Only Detonated		
4000	27	72	70	67	65			
4500	20	47	50	42	45			

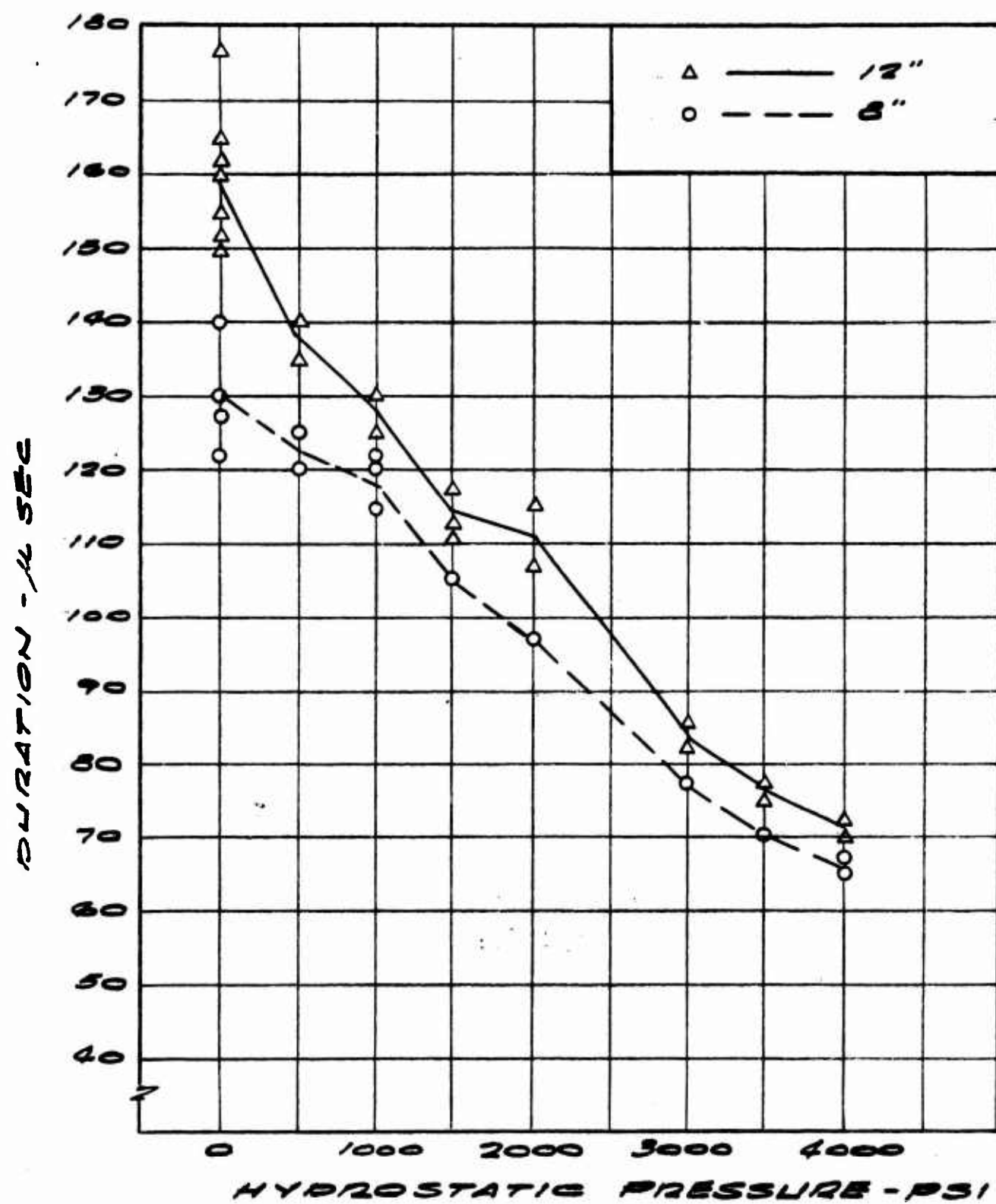


FIGURE 7. DURATION OF POSITIVE PRESSURE PHASE OF SHOCK WAVE FROM 14.7 TO 14.8-GM CHARGES OF PENTOLITE AS A FUNCTION OF HYDROSTATIC PRESSURE

TABLE III
SUMMARY OF IMPULSE PER UNIT AREA
FOR 13.7-GM CHARGES

Ambient Press., psi	Shot No.	12" TOP GAUGES		8" BOTTOM GAUGES		Comments
		Impulse #sec/in ²	Impulse #sec/in ²	Impulse #sec/in ²	Impulse #sec/in ²	
0	1	-	-	-	-	External Amplifier Early Reflection
500	5	-	-	-	-	
500	6	-	-	-	-	
0	7	-	-	-	-	Early Reflection
0	8	-	-	.304	.312	
0	10	.191	.200	.281	.306	
1000	9	.173	.162	.278	.285	
0	13	.194	.198	.277	-	
0	17	-	.212	.299	.273	
0	18	.180	.212	.216	.246	
1500	12	.180	.183	.249	.218	
1500	16	.153	.141	.217	.245	
2000	14	.152	.155	-	.245	
3000	15	.125	.099	.162	.188	
3500	19	.097	.127	-	.163	
0	21	-	.21	.283	.280	
0	26	.178	.183	.283	.246	
500	23	.188	.191	.283	.262	
1000	22	.161	.181	.233	.227	No Air Blanket
4000	27	.103	.100	.150	.154	Cap Only Detonated
4500	20	-	-	-	-	

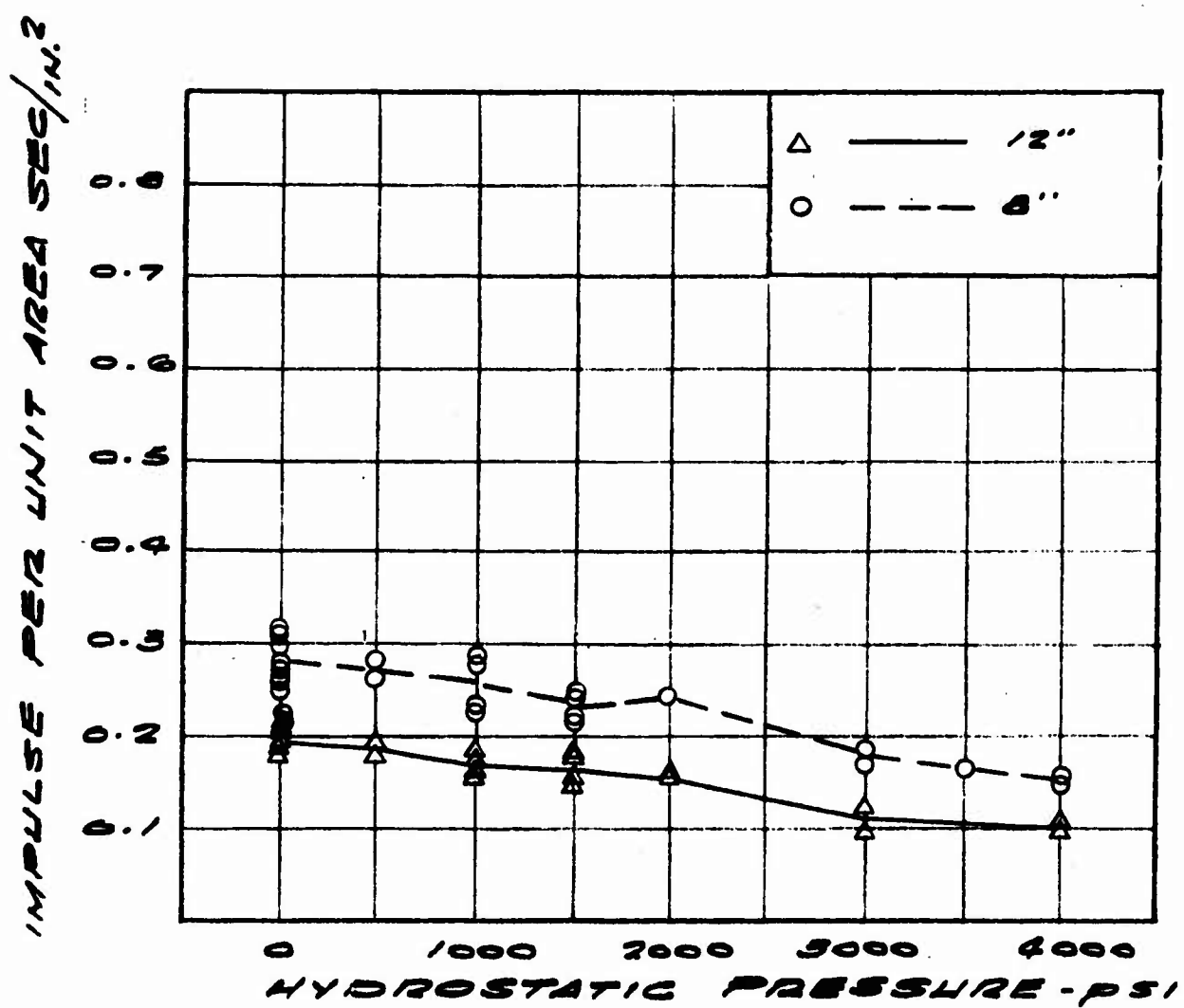


FIGURE 8. IMPULSE PER UNIT AREA AT 8 INCHES AND 12 INCHES FROM 14.7 TO 14.8-GM PENTOLITE CHARGES DETONATED AT VARIOUS HYDROSTATIC PRESSURES

TABLE IV

SUMMARY OF NEGATIVE PRESSURES FOR 13.7-GM CHARGES

Ambient Press., psi	Shot No.	12"		8"		Comments
		Press., psi	Press., psi	Press., psi	Press., psi	
0	1	-	-	-	-	
500	5	-	-	-	-	
500	6	-	-	-	-	
0	7	-	-	-	-	
0	8	-	-	-	-	
0	10	-	-	-	-	
1000	9	-	-	-	-	
0	13	-	-	-	-	
0	17	-	-	-	-	
0	18	-	-	-	-	
1500	12	139	142	279	275	
1500	16	-	-	279	275	
2000	14	139	142	-	-	
3000	15	559	567	1090	825	
3500	19	669	710	-	1380	
0	21	-	-	-	-	
0	26	-	-	-	-	
500	23	-	-	-	-	
1000	22	-	-	-	-	
4000	27	1090	1050	1600	1700	
4500	20	279	284	557	550	Cap Only Detonated

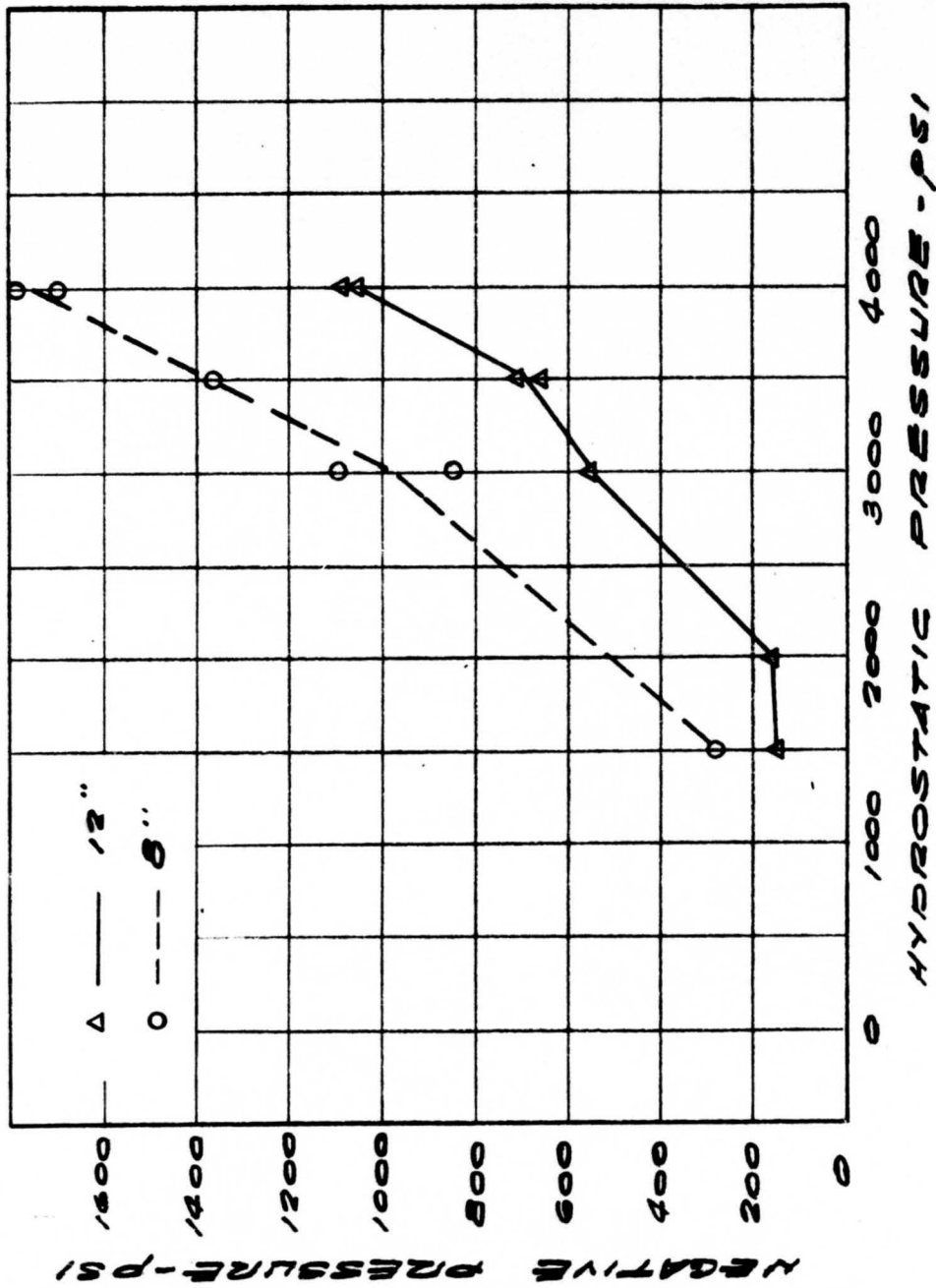


FIGURE 9. NEGATIVE PRESSURE AT 8 INCHES AND 12 INCHES
FROM 14.7 TO 14.8-GM PENTOLITE CHARGES DETONATED
AT VARIOUS HYDROSTATIC PRESSURES

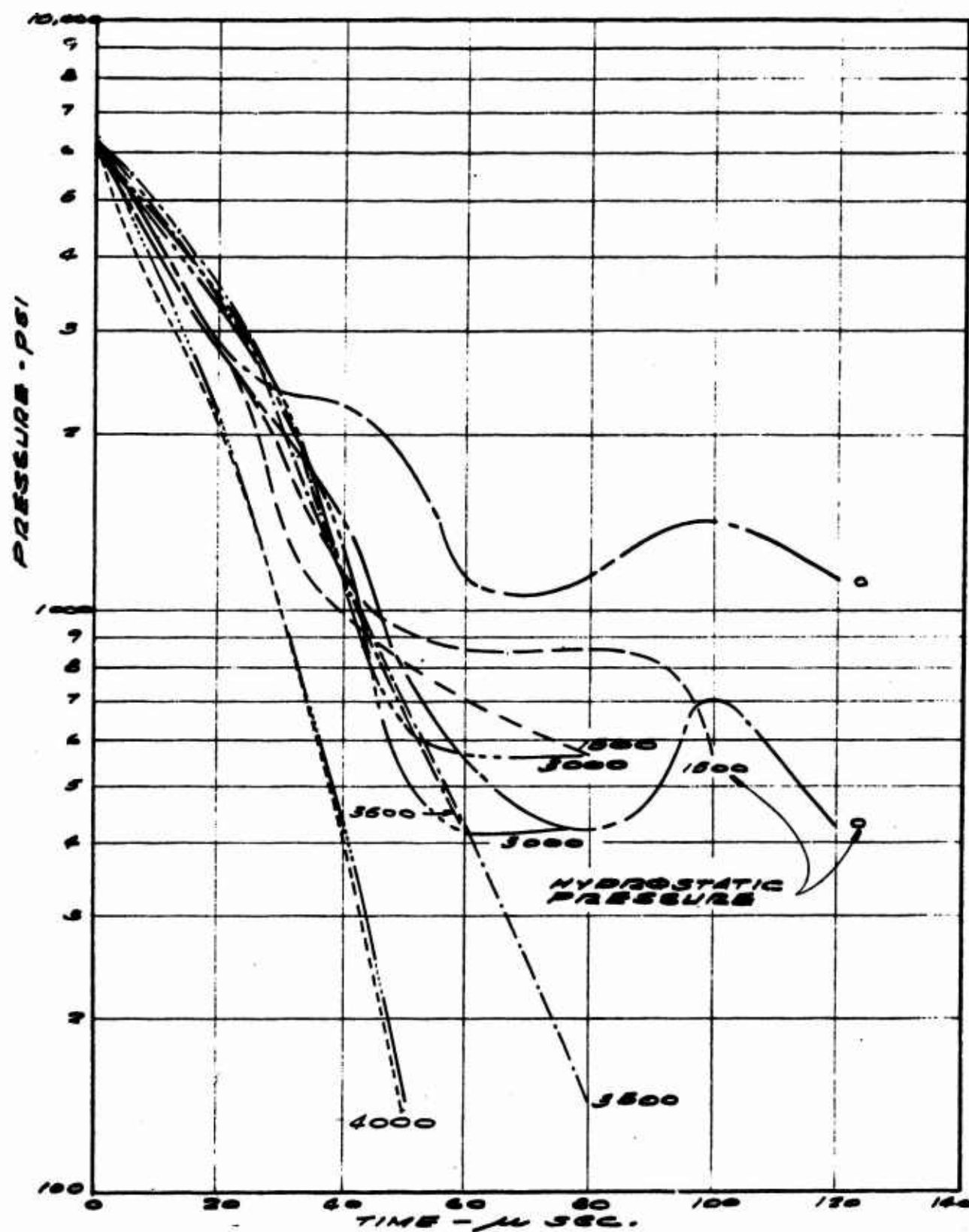


FIGURE 10. SUMMARY OF SHOCK OVERPRESSURES 12 IN. FROM CENTER OF 14.7 TO 14.8 CM PENTOLITE CHARGES DETONATED UNDER VARIOUS HYDROSTATIC PRESSURES AS A FUNCTION OF TIME

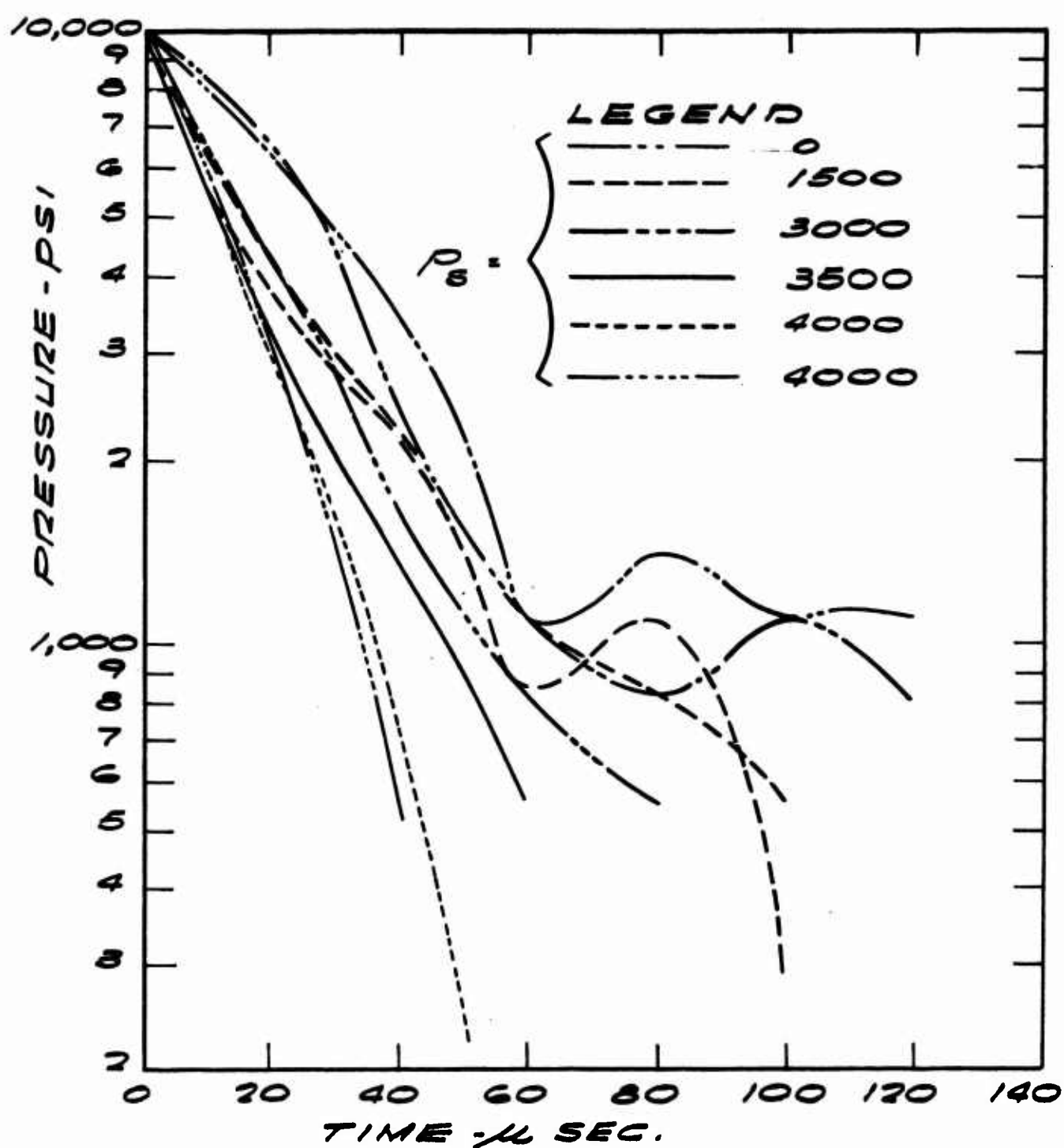


FIGURE 11. SUMMARY OF SHOCK OVERPRESSURES 8 INCHES FROM CENTER OF 14.7 TO 14.8-GM PENTOLITE CHARGES DETONATED UNDER VARIOUS HYDROSTATIC PRESSURES AS A FUNCTION OF TIME

A series of tests was made with seven and one-half -gm spherical Pentolite charges to determine whether or not the trends noted on pulse duration, impulse per unit area and negative pressure magnitude could be obtained with a smaller charge as the hydrostatic pressure varied. Data from these shots are shown in Appendix B, except for bubble pulse observations which are grouped in Appendix C. Figure 12 shows again that the peak shock overpressure is not noticeably affected by an increase of hydrostatic pressure. In Figure 13, the duration of the positive pressure phase is seen to decrease as the hydrostatic pressure increases. The same is true for the impulse per unit area, as is indicated in Figure 14. The negative pressure increases, however, as the hydrostatic pressure increases (Figure 15). It should be remembered that the negative pressure indicates the amount by which the shock pulse decreases below the hydrostatic level. To summarize, it is seen that the data in Figures 12 through 15 reinforce the observations presented in Figures 8 through 11.

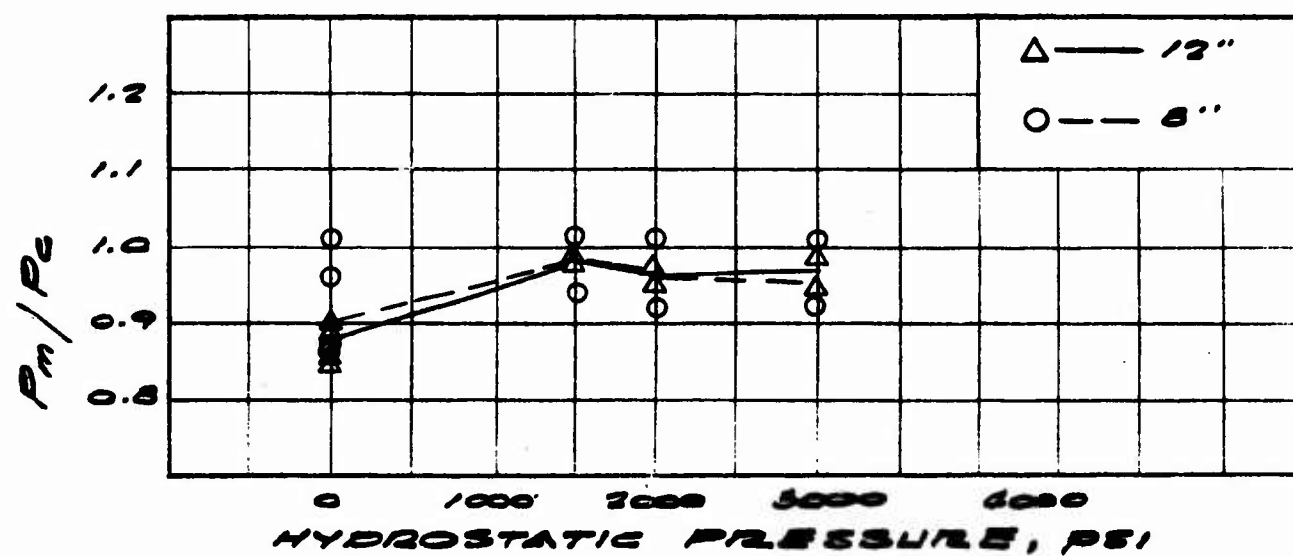


FIGURE 12. RATIO OF MEASURED TO CALCULATED PEAK PRESSURE FROM 7.4-GM PENTOLITE CHARGES AS A FUNCTION OF HYDROSTATIC PRESSURE

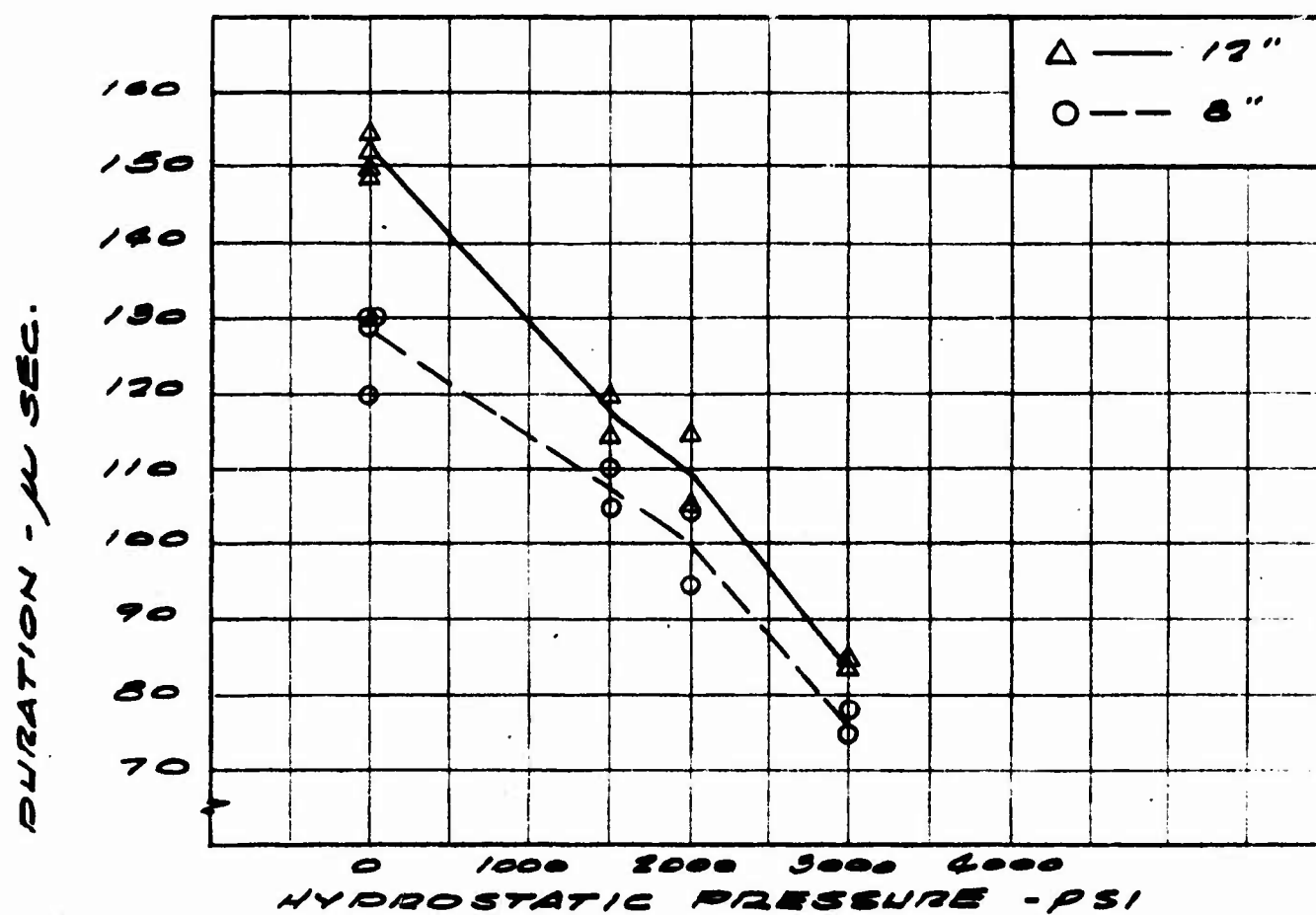


FIGURE 13. DURATION OF POSITIVE PRESSURE PULSE FROM 7.4-GM PENTOLITE CHARGES DETONATED AT VARIOUS HYDROSTATIC PRESSURES

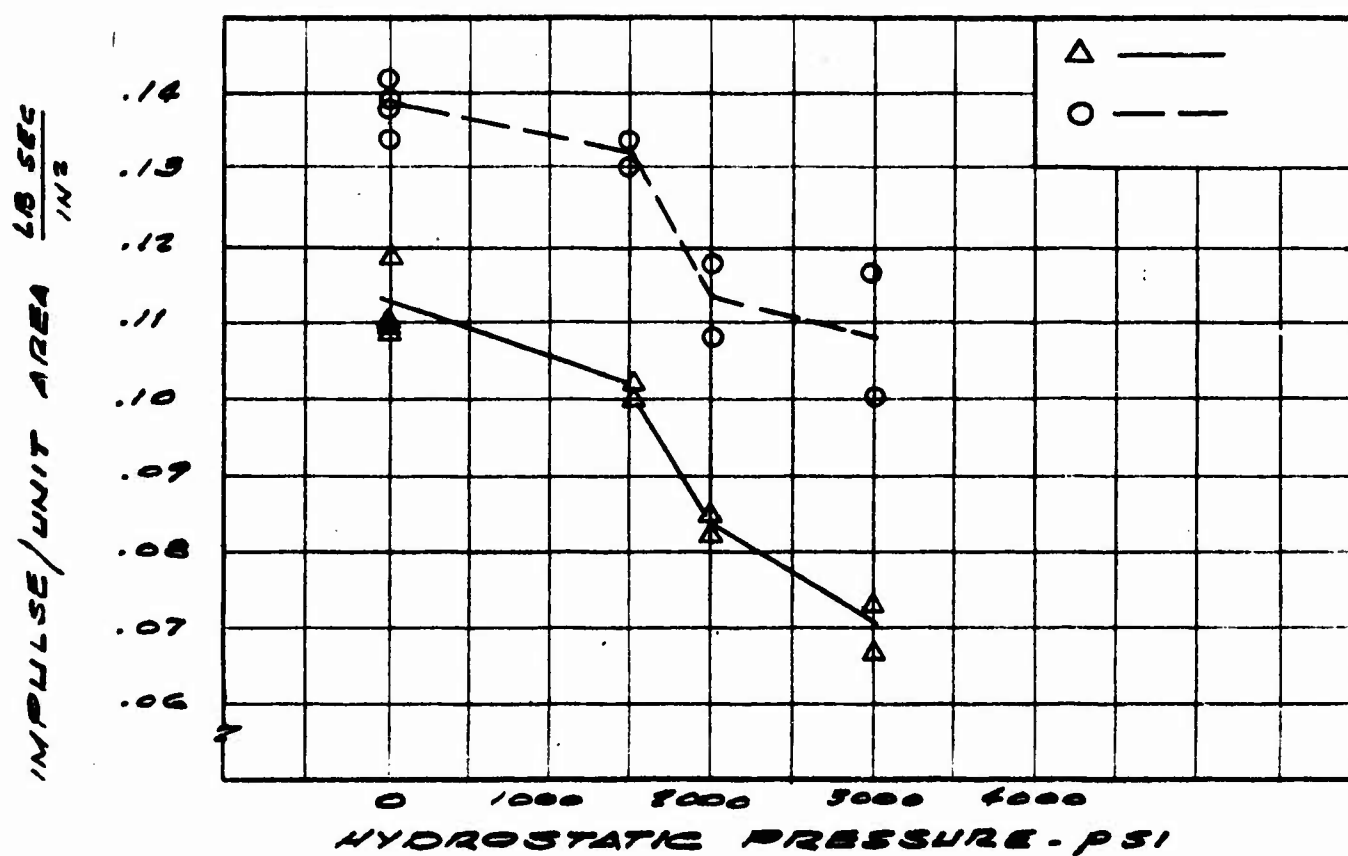


FIGURE 14. UNIT IMPULSE AT 8 INCHES AND 12 INCHES FROM
7.4-GM PENTOLITE CHARGES DETONATED AT
VARIOUS HYDROSTATIC PRESSURES

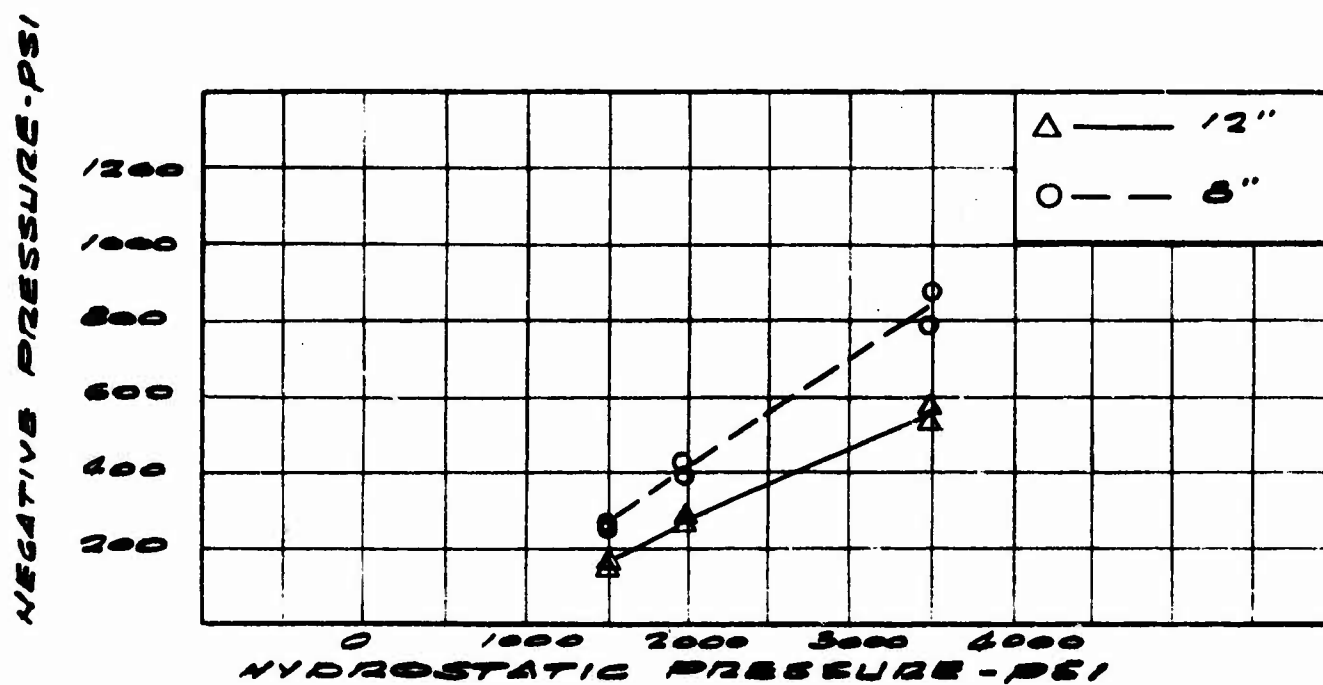


FIGURE 15. NEGATIVE PRESSURES FROM 7.4-GM PENTOLITE CHARGES DETONATED AT VARIOUS HYDROSTATIC PRESSURES

V. BUBBLE PULSE MEASUREMENTS

Measurement of bubble pulse characteristics as affected by increasing hydrostatic pressure is considerably more difficult than observations of the primary pressure pulse under similar circumstances, especially within pressure vessels. Even under "free field" conditions in the open ocean, close-in measurements of pressures from bubble pulsations are difficult to perform, and reproducible results under supposedly identical conditions are seldom achieved⁽⁴⁾.

The Willis formula for bubble pulse period⁽⁴⁾ is

$$T = \frac{k w^{1/3}}{(D + 33)^{5/6}}$$

where

T = period, sec.

W = charge weight, lbs.

D = depth, ft.

From this, the period of bubble oscillation for 7.4-gm Pentolite charge initiated by a J-2 electric blasting cap at a depth of five feet in a pressure tank is estimated to be about 56 milliseconds. In Figure 1C, the time from detonation until the first positive bubble pulse arrives at a distance of eight inches is about 40 milliseconds for two gauges. The time between the first and second oscillation is 54 milliseconds for both gauges. The magnitude of the peak pressure was overestimated, however,

so that the vertical deflection (indicating pressure magnitude) was not easily measured. Shots 1B through 5B were then made in the 30-inch tank. A third oscilloscope was used to record piezoelectric response at times corresponding to anticipated bubble pulse arrival for both the eight-inch position and the twelve-inch position. The shock pressures from these tests are shown in Appendix B and the bubble pulses are shown in Appendix C.

In Shot 1B the primary pressure pulse was lower than anticipated at all four gauge positions. The bubble pulse was also weaker than it should have been (Figure 2C). A second shot was made at zero confining pressure (Figure 3C), but again the peak bubble pressure was not even as high as indicated in Shot 1A.

In a third shot made in a 2,000-psi environment, the oscilloscope displaying the bubble pulse characteristic did not trigger. At 1,500 psi (Figure 4C), the peak pressure of the bubble pulse had increased to about 350 psi at 12 inches and 250 psi at 8 inches. It should be noted, however, that Gauge No. 3 at 8 inches was giving a low reading for the shock pressures in Shots 1B through 5B. The indication was, however, that the magnitude of the bubble pulse increased as the hydrostatic pressure increased.

Shot 5B was made at 3,000 psi and an allowance was made for an increase in bubble pressure on the third oscilloscope. As shown in

Figure 5C, the magnitude of the bubble pulse appeared to increase again with a further increase in pressure. To compare Figures 4C and 5C, it was necessary to estimate peak to peak deflection from Figure 5C. The recurring pressure peaks occur at intervals that agree with the calculated bubble period for the respective pressures. In both figures, however, the initial portion of the sweep is unreadable. This is due in part to the overshoot caused by the high shock pressure arriving immediately after detonation. Other spurious signals were probably caused by gauge accelerations and pressure reflections.

In an attempt to improve the bubble pulse detail, additional tests were performed in a larger vessel with a four-foot diameter. Hydrostatic levels in this tank were limited to 500 psi due to the shock pressure anticipated at the vessel wall. The charge and one gauge were positioned as nearly as possible on the vessel centerline. For the first few tests, a second gauge was positioned four inches from the centerline gauge and at the same distance from the charge as the first gauge. The output from the centerline gauge, which was above the charge and positioned with wires, was transmitted to two oscilloscopes, one of which was on a slow sweep rate so as to display secondary pressure pulses. As shown in Figure 6C, the bubble period corresponded fairly closely to the anticipated period. Maximum bubble pressure was about 465 psi, peak to peak. The primary pressure pulse indicated a peak pressure of about 8000 psi when the record was illuminated by light.

In Shot 7B (Figure 7C), the bubble pulse period again was in close agreement with the calculated value; but the peak to peak value of the pressure pulse appeared to be about 290 psi. If the thin, faint spike of the bubble pulse in Figure 6C is neglected, the bubble pulse values obtained in the two shots agree reasonably well. The peak values of the initial shock wave were larger than would be anticipated, but the reflection from the vessel wall was lower than it previously had been.

Prior to Shot 8B, a two-foot wide section of flat steel mesh was placed two inches from the vessel wall symmetrically around the charge. The arrangement is shown in Figure 16. One gauge was placed on the vessel centerline, while a second gauge was placed between the vessel wall and the mesh. In Shot 8B (as shown in Figure 8C), the reflection was minimized and the pressure outside the mesh was about 1690 psi; whereas it was calculated to be 2280 psi. Similar results were obtained in Shot 9B (Figure 9C).

Shot 10B (Figure 10C) was made at 500 psi. In this instance the peak shock pressure was lower than anticipated at eight inches, but the bubble pulse period was reasonably close to the expected value. Equivalent results were again obtained in Shot 11B (Figure 11C), which was made at 500 psi.

To try to reduce the vibrations, it was decided to move the centerline gauge farther from the charge. Shot 12B (Figure 12C), also made

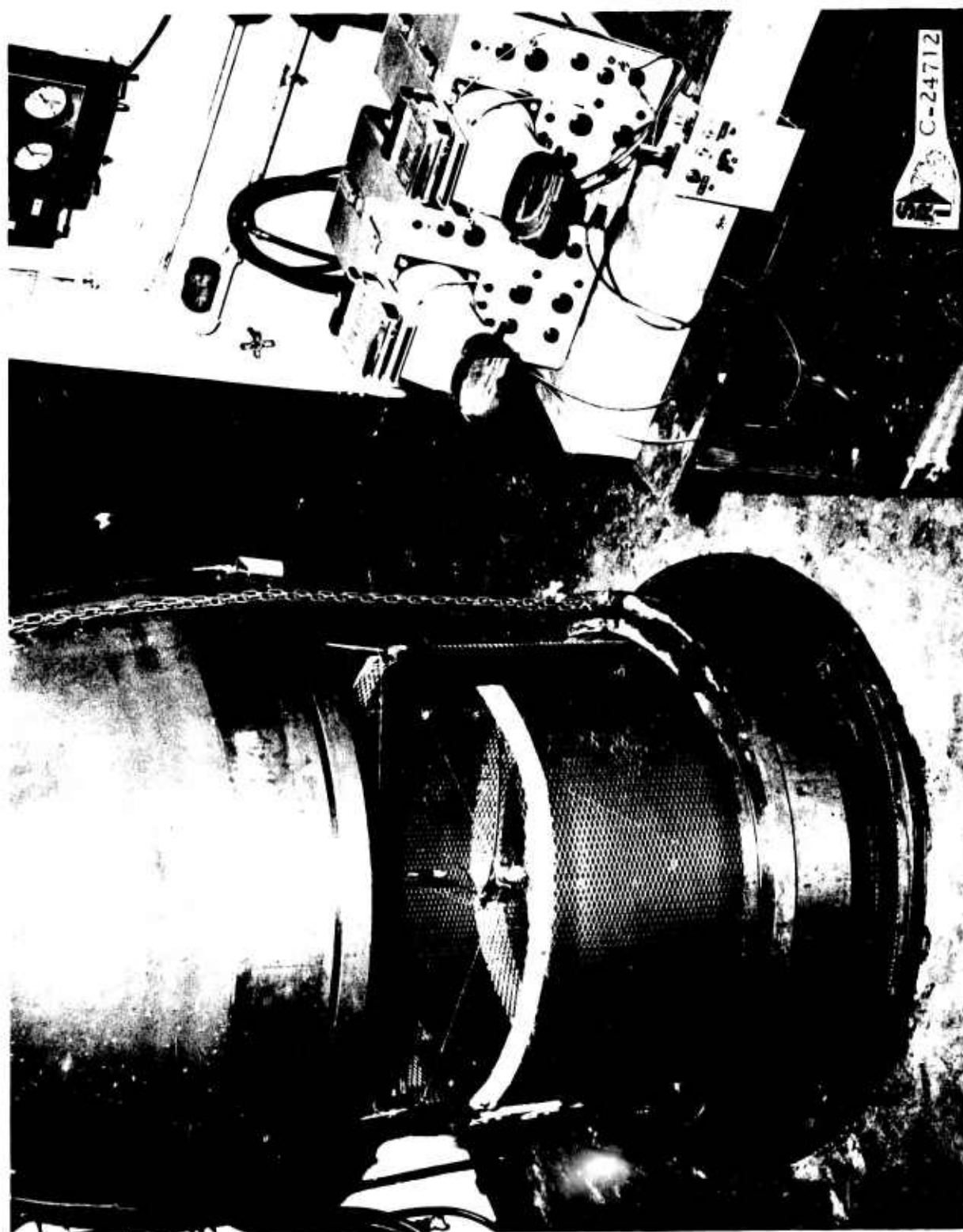


FIGURE 16. LARGE DIAMETER PRESSURE VESSEL

at 500 psi, indicated that some reduction in random vibration was achieved. A final pressurized shot, No. 13B (Figure 13C) was accomplished with the bubble pulse gauge positioned 15 inches from the charge. A slight improvement in clarity of detail was achieved, but it was still necessary to compare the results with zero pressure shots on a peak to peak basis. Shot 14B (Figure 14C) was made at 20 psi with instrument positions the same as they were in Shot 13B except for the sweep speed of the oscilloscope displaying the bubble pulse. This shot was made at 20 psi to provide a bubble pulse under near-zero psi conditions but with enough pressure to provide some of the stability afforded the tank under the higher pressure shots. The spike of the bubble pulse indicated a pressure of 240 psi, which is somewhat greater than the bubble pressures measured at zero confining pressure.

From the above discussion of the data presented in Appendix C, it is obvious that measurement of bubble pulse characteristics at high pressures within a pressurized tank is impeded by reflections from the tank walls and vibration of the gauge positioning device, which is usually a cantilevered rod, or two wires spanning the distance between two pipes. At zero confining pressure, the bubble pulse arrives after much of the random vibration has ceased, even at the close-in distances of interest. At higher pressures, however, the pulses occur so quickly that random vibrations do not have time to dissipate. Apparently, bubble pulses are

difficult to observe close to the charge even under free-field conditions at shallow depths⁽⁴⁾, but at greater depths and pressures, water motion and random agitation from the primary shock wave compounds the problem.

Two qualitative trends appear to emerge from the data: (a) the peak to peak magnitude of the bubble pulse seemingly increases as the hydrostatic pressure increases and (b) the bubble pulse appears as a continuous vibration at greater depths.

VI. ADVANTAGES AND LIMITATIONS OF PRESSURE VESSELS FOR STUDYING UNDERWATER EXPLOSIONS

For small charges detonated at great depths, pressure vessels offer an economic advantage over free-field tests in the ocean. Also, a technical advantage is achieved in the shorter leads used to transmit the pulse characteristics from the sensing device within the vessel to a recording system. Further, there is a convenience factor in having a fixed site for experimentation.

These advantages are rather straightforward for observations of pressure pulses which occur prior to the arrival of wall reflections at the point of interest. Of course, the larger the vessel diameter, the less the depth that can be simulated for a given vessel wall thickness. Pulses which occur at a relatively long interval after the arrival of the initial shock wave do not appear to be distorted by the previously occurring reflections; but these reflections can conceivably distort the bubble source which gives rise to the later pulsations.

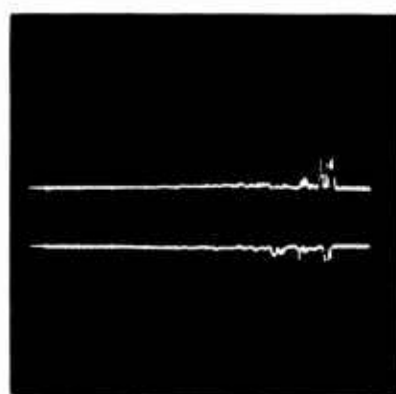
At higher pressures, the bubble pulses arrive while the gauge positioning devices are still vibrating and accelerating the tourmaline transducers. Also, reflections have not completely died out upon the arrival of the first pulse. Correction of the observed pressures for the myriad of reflections and vibrations would be both complex and questionable.

In the current study two attempts were made to reduce the reflected pressure and protect the vessel wall. The wire mesh shown in Figure 16

was used in several shots, but the results were erratic, both with respect to the pressure transmitted through the mesh and the reflected pressure. The center gauge was positioned with a cantilevered rod for Shots 11B through 14B. In Figures 10C and 11C, the reflections and pressure transmitted through the mesh were equivalent, so that no effect was introduced by removing the wire previously used to hold the gauges. In subsequent tests, however, the reflected pressure was unusually large and the pressure transmitted through the mesh appeared to increase.

Another attempt to dampen the reflection involved the use of air bubbles adjacent to the tank wall. A ring of copper tubing with one-eighth-inch holes every two inches was placed around the inside of the vessel at the bottom, and air was bubbled up the tank walls prior to and during detonation. Unfortunately, a small circulation was introduced in the tank, so that the pressure pulses (shown in Figure 17) were distorted; but reflection from the tank wall was not observed.

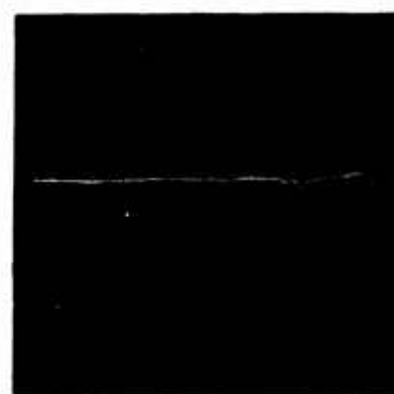
To summarize, it appears that a means for minimizing shock reflection from the vessel wall is possible but needs further investigation. Different types of mesh and bubble arrangements should be investigated. Also, gauge positioning devices in pressure vessels are critical for studying secondary pulses in that they must be small so as not to interfere with the primary shock wave but must be sturdy so as to resist vibrations and reflections occurring prior to or during the arrival of secondary pulses.



536

533

100 μ sec/cm, 0.5 v/cm
Bottom Gauges



533

10 msec/cm, .02 v/cm
Bubble Pulse

Comments: Air bubbled around vessel wall.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Bottom Gauges</u>		<u>Bubble Pulse</u>
	<u>536</u>	<u>533</u>	<u>533</u>
Distance, in.	8	8	8
Deflection, cm.	1.0	1.3	-
Measured press., psi	2690	3560	-
Calc. press., psi	7950	7950	-
Calculated period, msec	-	-	57
Measured period, msec	-	-	24

Figure 17. Effect of Bubbles on Reflection
From Tank Walls

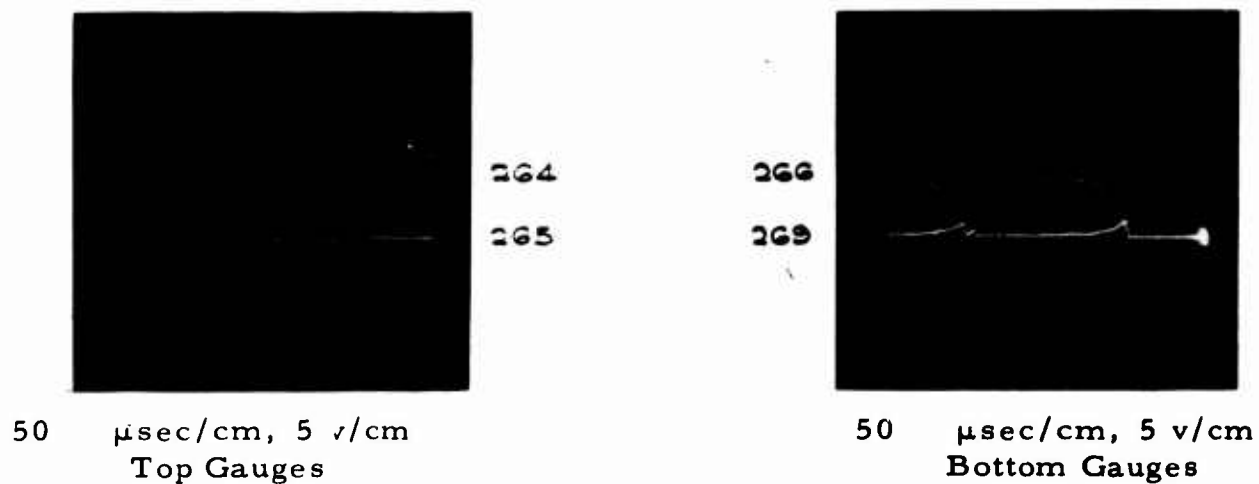
LIST OF REFERENCES

1. Blaik, M. and Christian, E.A., "Pressure Pulses of Small Explosions at Great Depths in the Ocean," 68th Meeting, Acous. Soc. Am., Austin, Texas, October 1964.
2. Christian, E.A. and Blaik, M., "Energy Spectra of Small Explosions at Great Depths," 68th Meeting, Acous. Soc. Am., Austin, Texas, October 1964.
3. Vanzant, B.W., DeHart, R.C., and Matson, P.E., "High Pressure, Shock Resistant Seal for Coaxial Cable," Rev.Sci.Instr., Vol. 36, No. 1, 1965, pp. 107-8.
4. Cole, R.H., Underwater Explosions, Princeton University Press, Princeton, New Jersey, 1948.

APPENDIX A

OSCILLOSCOPE RECORDS OF TESTS
WITH 13.7-GM PENTOLITE CHARGES

Note: The suspension frame shown in Figure 5 was used for all tests noted in Appendix A. The two top gages were 12 inches from the charge center (unless otherwise noted) and the bottom gages were at a distance of 8 inches.

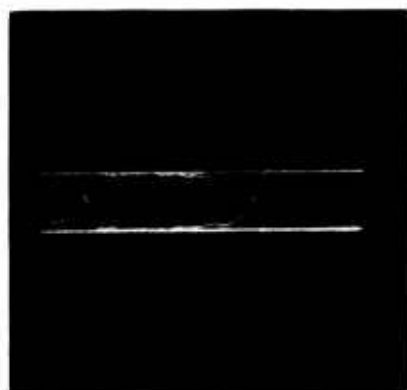


Comments: External amplifier, early reflection

Charge Weight: 13.7 gms pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	8-3/4	8-3/4	9	9-3/8
Deflection, cm.	1.75	1.80	2.00	0.55
Measured press., psi	7370	9040	8210	-
Calc. press., psi	8850	8850	8550	8190
Area, cm ²	-	-	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	-	-
Duration, μsec	-	-	127	125
Negative press., psi	-	-	-	-

Figure 1A, Shot 1, Zero psi

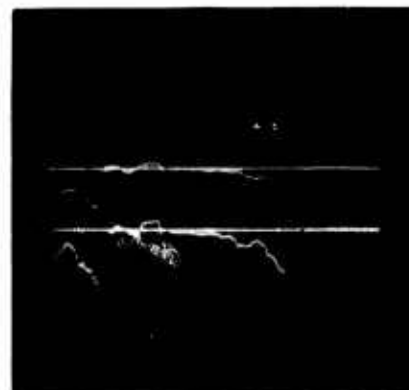


264

265

50 $\mu\text{sec/cm}$, 5 v/cm

Top Gauges



266

269

50 $\mu\text{sec/cm}$, 266- 5 v/cm,
269- 2 v/cm

Bottom Gauges

Comments: External amplifier, early reflection

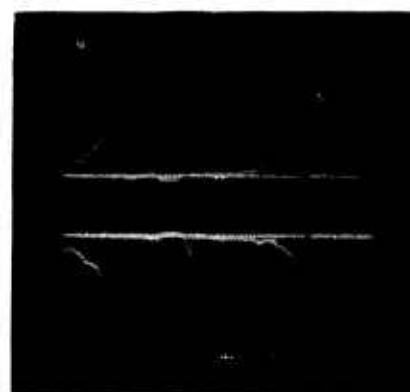
Charge Weight: 13.6 gms pentolite + J-2 cap = 14.7 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	11-1/4	11-1/4	8-5/8	8-7/8
Deflection, cm.	1.65	1.50	2.35	-
Measured press., psi	6550	6640	8490	-
Calc. press., psi	6640	6640	9000	-
Area, cm^2	-	-	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	-	-
Duration, μsec	130	132	-	-
Negative press., psi	-	-	-	-

Figure 2A, Shot 5, 500 psi



50 $\mu\text{sec/cm}$, 5 v/cm
Top Gauges



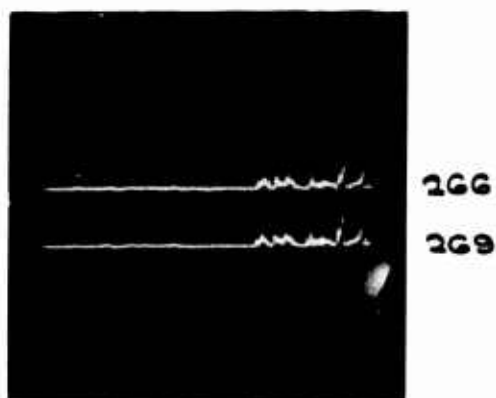
50 $\mu\text{sec/cm}$, 5 v/cm
Bottom Gauges

Comments: External amplifier, early reflection

Charge Weight: 13.7 gms pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	10	10	8-1/4	8-1/4
Deflection, cm.	1.80	1.75	2.20	2.30
Measured press., psi	7100	7950	8400	11480
Calc. press., psi	7600	7600	9440	9440
Area, cm ²	-	-	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	-	-
Duration, μsec	130	130	112	122
Negative press., psi	-	-	-	-

Figure 3A, Shot 6, 500 psi



0.5 msec/cm, 1.0 v/cm

Comments: Scope amplifier, early reflection slow sweep

Charge Weight: 13.8 gms pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	-	-	8-3/4	8-3/4
Deflection, cm.	-	-	1.65	1.65
Measured press., psi	-	-	8820	9040
Calc. press., psi	-	-	8870	8870
Area, cm ²	-	-	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	-	-
Duration, μsec	-	-	-	-
Negative press., psi	-	-	-	-

Figure 4A, Shot 7, Zero psi



50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



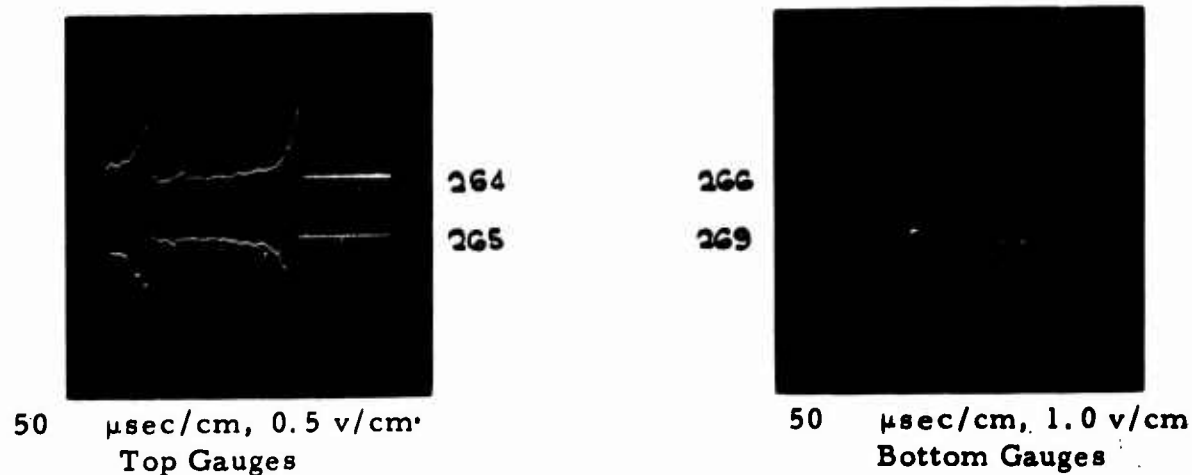
50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: Early reflection

Charge Weight: 13.8 gms pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.25	2.20	1.80	1.80
Measured press., psi	6010	6080	9640	9860
Calc. press., psi	6210	6210	9810	9810
Area, cm ²	-	-	1.14	1.14
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	.304	.312
Duration, μsec	-	-	140	130
Negative press., psi	-	-	-	-

Figure 5A, Shot 8, Zero psi

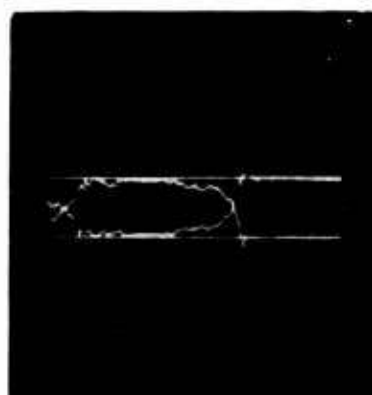


Comments: Early reflection

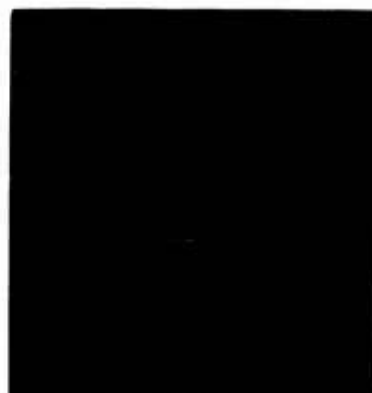
Charge Weight: 13.8 gms pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.30	2.20	1.80	1.85
Measured press., psi	6120	6090	9640	10,130
Calc. press., psi	6210	6210	9810	9810
Area, cm ²	1.30	1.17	1.04	1.04
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.173	.162	.278	.285
Duration, μsec	125	125	122	115
Negative press., psi	-	-	-	-

Figure 6A, Shot 9, 1000 psi



50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



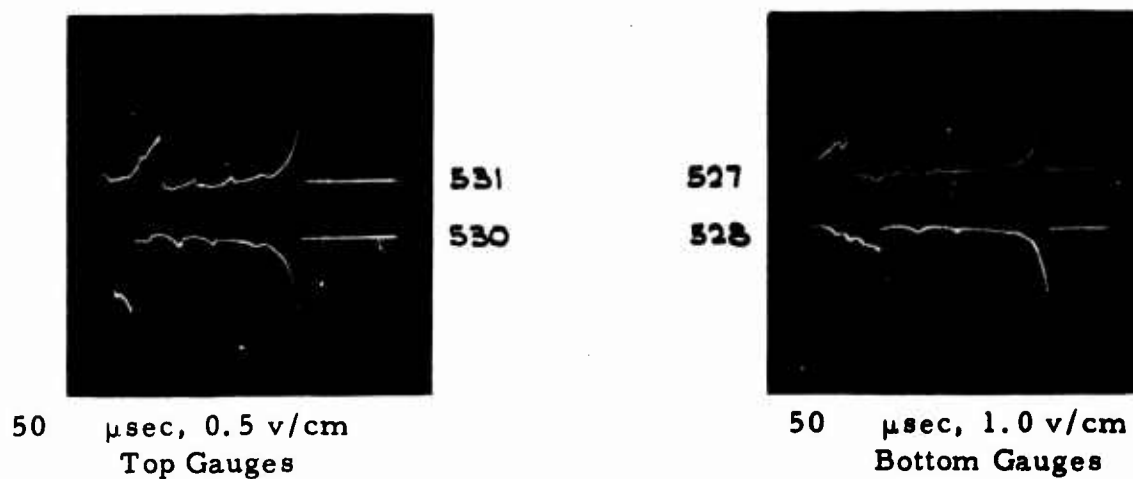
50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: Early reflection

Charge Weight: 13.7 gms pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>264</u>	<u>265</u>	<u>266</u>	<u>269</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.25	2.15	1.80	1.75
Measured press., psi	6050	6000	9700	9680
Calc. press., psi	6190	6190	9750	9750
Area, cm ²	1.43	1.43	1.04	1.11
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.191	.200	.281	.306
Duration, μsec	-	-	-	-
Negative press., psi	-	-	-	-

Figure 7A, Shot 10, Zero psi

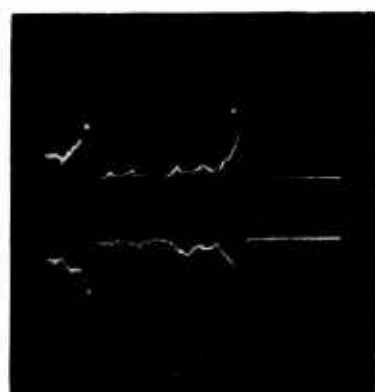


Comments: Early reflection

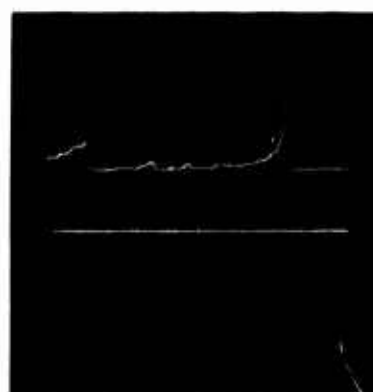
Charge Weight: 13.8 gms pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>527</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.5	2.4	1.75	1.95
Measured press., psi	6990	6810	9760	10,700
Calc. press., psi	6210	6210	9810	9810
Area, cm ²	1.29	1.29	.891	.794
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.180	.183	.249	.218
Duration, μ sec	117	112	105	105
Negative press., psi	139	142	279	275

Figure 8A, Shot 12, 1500 psi



50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: Gauges on cap side of charge

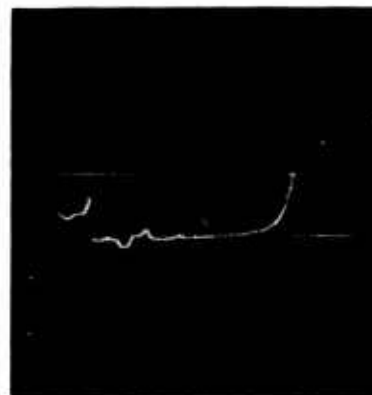
Charge Weight: 13.8 gms pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>527</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.35	2.75	1.90	-
Measured press., psi	6560	6440	10,600	-
Calc. press., psi	6210	6210	9810	-
Area, cm ²	1.39	1.39	.992	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.194	.198	.277	-
Duration, μsec	155	150	127	-
Negative press., psi	-	-	-	-

Figure 9A, Shot 13, Zero psi



50 μ sec, 0.5 v/cm
Top Gauges



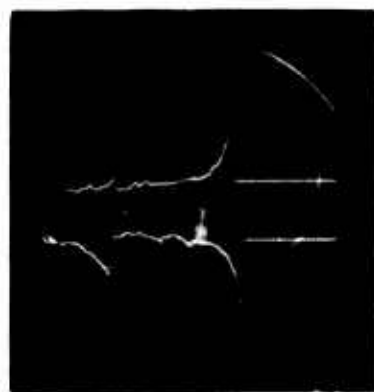
50 μ sec, 1.0 v/cm
Bottom Gauges

Comments: Gauges on cap side of charge

Charge Weight: 13.6 gms pentolite + J-2 cap = 14.7 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>527</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.4	2.35	-	1.85
Measured press., psi	6700	6680	-	10,200
Calc. press., psi	6190	6190	-	9760
Area, cm ²	1.09	1.09	-	.892
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.152	.155	-	.245
Duration, sec	115	107	-	97
Negative press., psi	139	142	-	-

Figure 10A, Shot 14, 2000 psi



50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



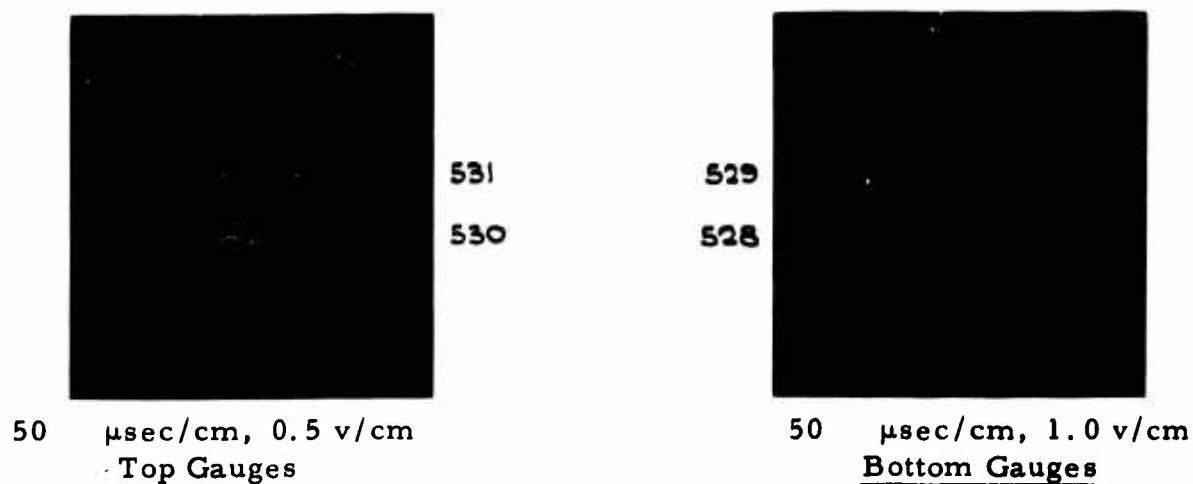
50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: None

Charge Weight: 13.7 gms pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>529</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.15	2.15	2.0	1.75
Measured press., psi	6000	6100	10,900	9630
Calc. press., psi	6190	6190	9750	9750
Area, cm^2	.894	.695	.694	.69
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.125	.099	.162	.188
Duration, μsec	82	85	77	77
Negative press., psi	559	567	1090	825

Figure 11A, Shot 15, 3000 psi

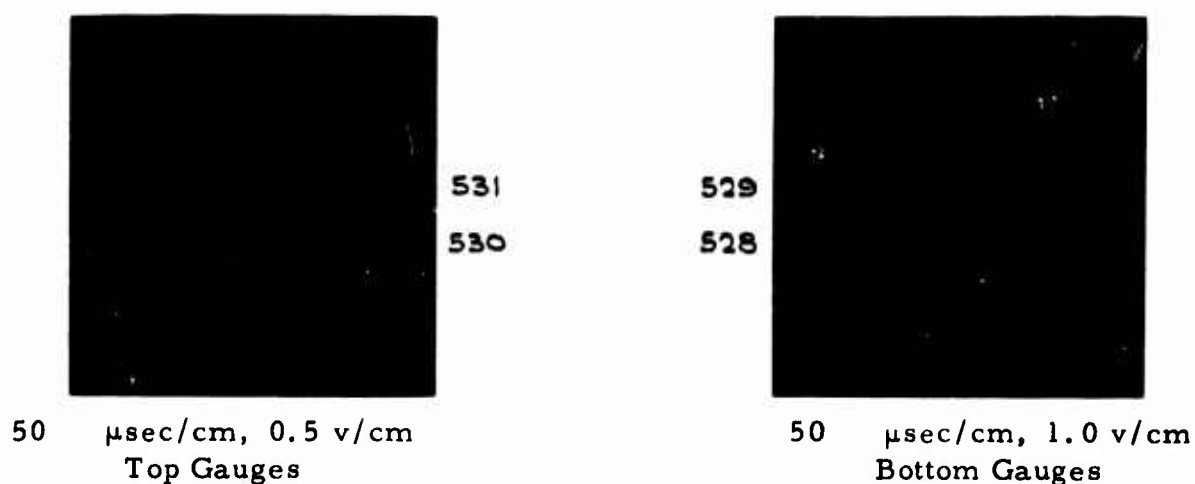


Comments: Peak response darkened by timing mark

Charge Weight: 13.65 gms pentolite + J-2 cap = 14.75 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>529</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.2	2.15	1.8	1.75
Measured press., psi	6150	6100	9800	9620
Calc. press., psi	6190	6190	9750	9750
Area, cm^2	1.09	.992	.795	.894
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.153	.141	.217	.245
Duration, μsec	112	110	105	105
Negative press., psi	-	-	279	275

Figure 12A, Shot 16, 1500 psi

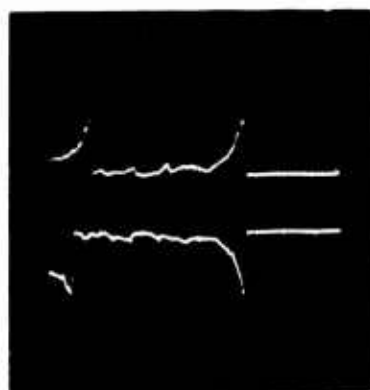
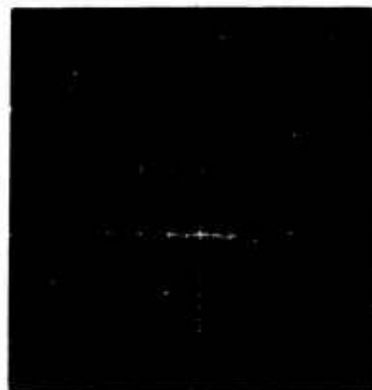


Comments: Peak response darkened by timing mark

Charge Weight: 13.6 gms pentolite + J-2 cap = 14.7 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>529</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	-	2.35	1.9	1.75
Measured press., psi	-	6660	10,350	9630
Calc. press., psi	-	6190	9760	9760
Area, cm ²	-	1.49	1.09	.992
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	.212	.299	.273
Duration, μsec	-	162	127	127
Negative press., psi	-	-	-	-

Figure 13A, Shot 17, Zero psi

50 $\mu\text{sec/cm}$, 0.5 v/cm50 $\mu\text{sec/cm}$, 1.0 v/cm

Comments: None

Charge Weight: 13.6 gms pentolite + J-2 cap = 14.7 gms

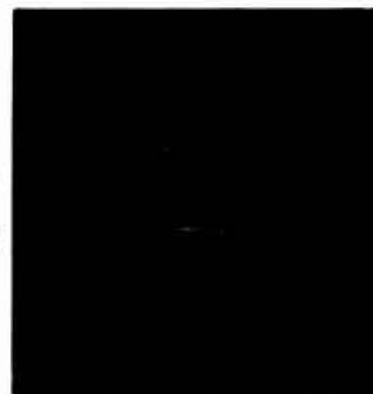
	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>529</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm	2.15	2.2	1.80	1.80
Measured press., psi	6010	6240	9800	9900
Calc. press., psi	6190	6190	9760	9760
Area, cm^2	1.29	1.49	.79	.89
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.18	.212	.216	.246
Duration, μsec	152	177	122	127
Negative press., psi	-	-	-	-

Figure 14A, Shot 18, Zero psi



531
530

50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



532
528

50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: Peak response darkened by timing mark

Charge Weight: 13.6 gms pentolite + J-2 cap = 14.7 gms

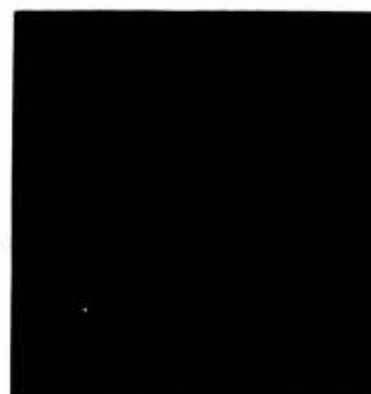
	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>532</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.25	2.2	-	1.8
Measured press., psi	6290	6240	-	9900
Calc. press., psi	6190	6190	-	9790
Area, cm^2	.695	.895	-	.595
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.097	.127	-	.163
Duration, μsec	75	77	-	70
Negative press., psi	699	710	-	1380

Figure 15A, Shot 19, 3500 psi



531
530

50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



534
528

50 $\mu\text{sec/cm}$, 1.0 v/cm
Bottom Gauges

Comments: Pentolite did not detonate

Charge Weight: J-2 cap = 1.1 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>531</u>	<u>530</u>	<u>534</u>	<u>528</u>
Distance, in.	12	12	8	8
Deflection, cm.	0.4	0.4	0.35	0.35
Measured press., psi	1120	1130	1950	1920
Calc. press., psi	2340	2340	3700	3700
Area, cm^2	-	-	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	-	-	-
Duration, μsec	47	50	42	45
Negative press., psi	279	284	557	550

Figure 16A, Shot 20, 4500 psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



50 μ sec/cm, 1.0 v/cm
Bottom Gauges

Comments: None

Charge Weight: 13.7 gms Pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>10</u>
Distance, in.	12	12	8	8
Deflection, cm.	-	2.15	2.10	1.60
Measured press., psi	-	6240	11215	9550
Calc. press., psi	6190	6190	9790	9790
Area, cm ²	-	1.44	1.06	1.00
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	-	0.21	0.283	0.280
Duration, μ sec	160	162	127	130
Negative press., psi	-	-	-	-

Figure 17A, Shot 21, Zero psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



50 μ sec/cm, 1.0 v/cm
Bottom Gauges

Comments: No air blanket on top

Charge Weight: 13.7 gms Pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>10</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.55	2.20	1.95	1.80
Measured press., psi	6950	6400	10,400	10,100
Calc. press., psi	6190	6190	9790	9790
Area, cm ²	1.19	1.25	.875	.811
Unit impulse $\frac{\# \text{ sec}}{\text{in}^2}$	0.161	0.181	0.233	0.227
Duration, μ sec	130	125	120	115
Negative press., psi	-	-	-	-

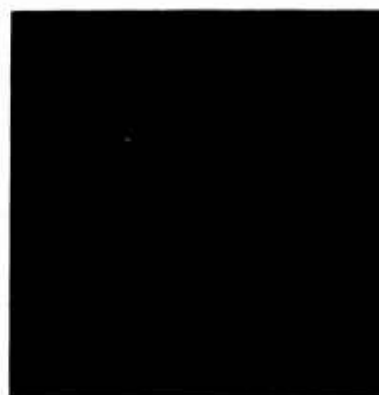
Figure 18A, Shot 22, 1000 psi



536

9

50 μ sec/cm, 0.5 v/cm
Top Gauges



8

10

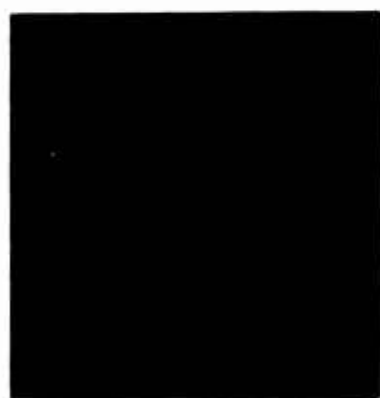
50 μ sec/cm, 0.5 v/cm
Bottom Gauges

Comments: None

Charge Weight: 13.7 gms Pentolite + J-2 cap = 14.8 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>10</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.25	2.20	1.85	1.75
Measured press., psi	6190	6410	9860	9840
Calc. press., psi	6190	6190	9790	9790
Area, cm ²	1.37	1.31	1.06	0.936
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.188	0.191	0.283	0.262
Duration, μ sec	140	135	125	120
Negative press., psi	-	-	-	-

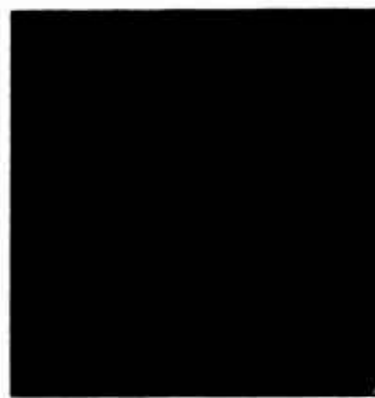
Figure 19A, Shot 23, 500 psi



7

9

50 μ sec/cm, 0.5 v/cm
Top Gauges



8

3

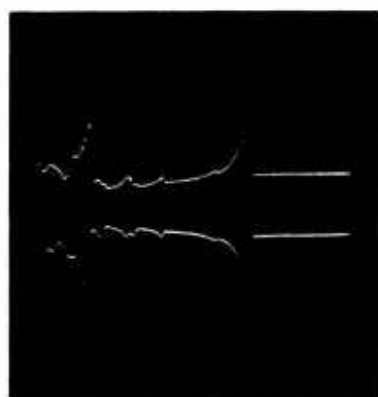
50 μ sec/cm, 0.5 v/cm
Bottom Gauges

Comments: None

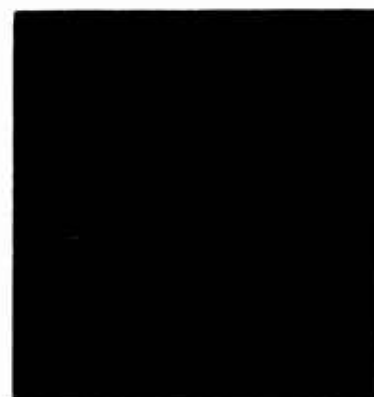
Charge Weight: 13.8 gms Pentolite + J-2 cap = 14.9 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.2	2.2	1.9	2.05
Measured press., psi	6000	6400	10150	10050
Calc. press., psi	6210	6210	9810	9810
Area, cm ²	1.31	1.25	1.06	1.00
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.178	0.183	0.283	0.246
Duration, μ sec	155	165	140	130
Negative press., psi	-	-	-	-

Figure 20A, Shot 26, Zero psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



50 μ sec/cm, 1.0 v/cm
Bottom Gauges

Comments: None

Charge Weight: 13.6 gms Pentolite + J-2 cap = 14.7 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	2.35	2.15	1.95	2.0
Measured press., psi	6410	6250	10150	9840
Calc. press., psi	6190	6190	9790	9790
Area, cm ²	0.75	0.687	0.563	0.625
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.103	0.10	0.150	0.154
Duration, μ sec	72	70	67	65
Negative press., psi	1090	1050	1600	1700

Figure 21A, Shot 27, 4000 psi

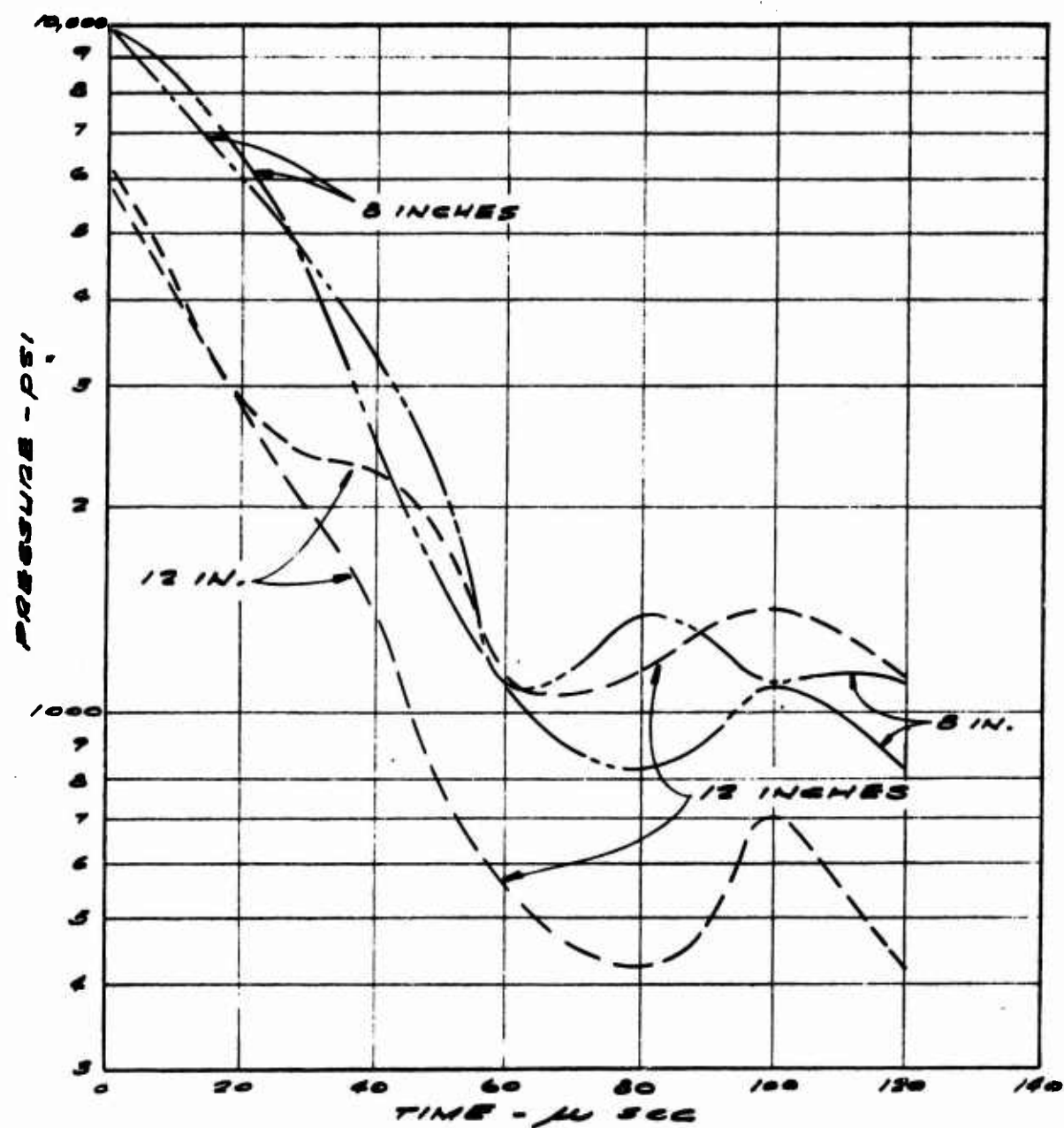


FIGURE 22A. PRESSURE VS TIME, FOR 14.7 GM PENTOLITE
CHARGE DETONATED AT 0 PSI
HYDROSTATIC PRESSURE

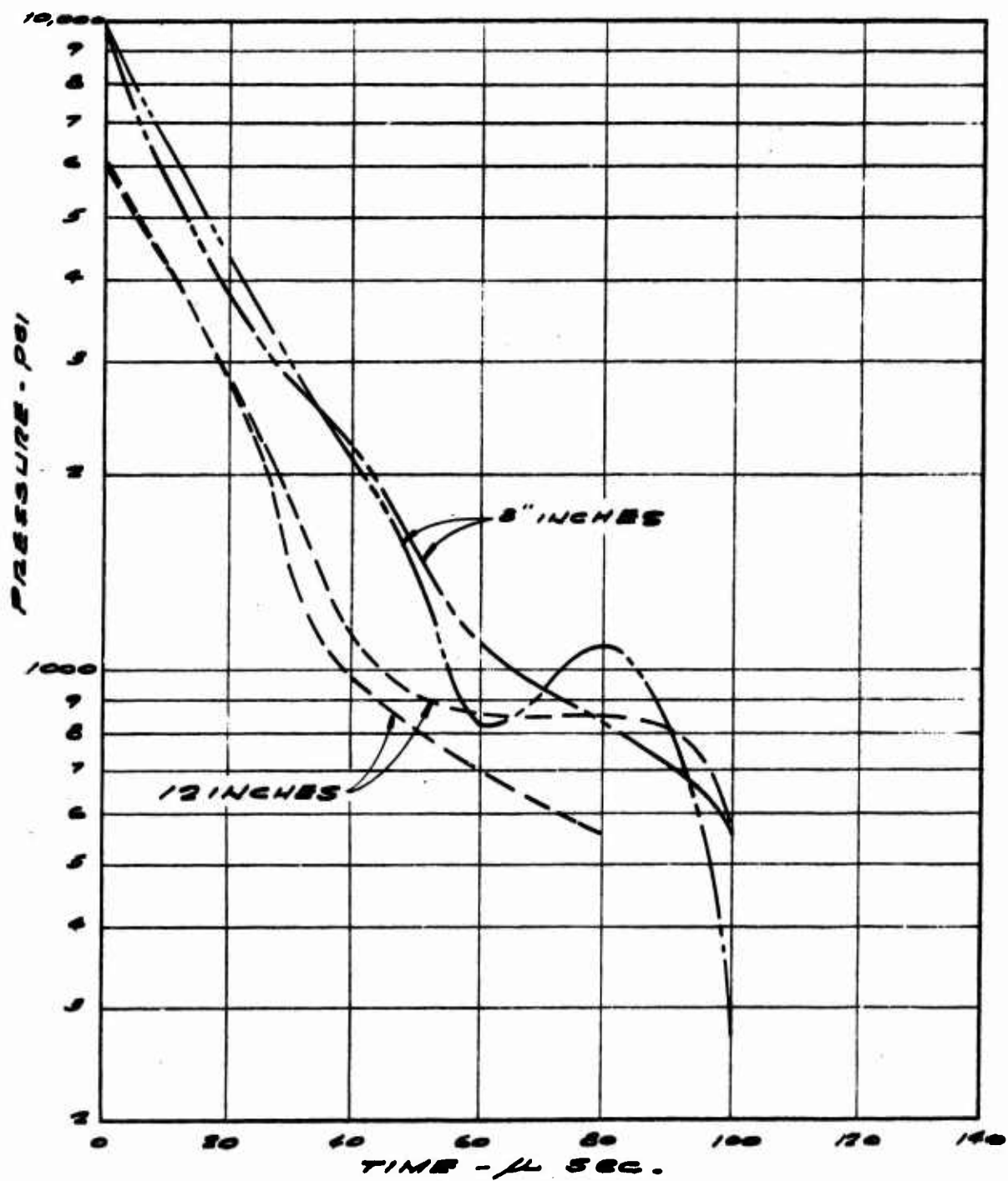


FIGURE 23A. PRESSURE VS TIME, FOR 14.75 GM PENTOLITE
CHARGE DETONATED UNDER 1500 PSI
HYDROSTATIC PRESSURE

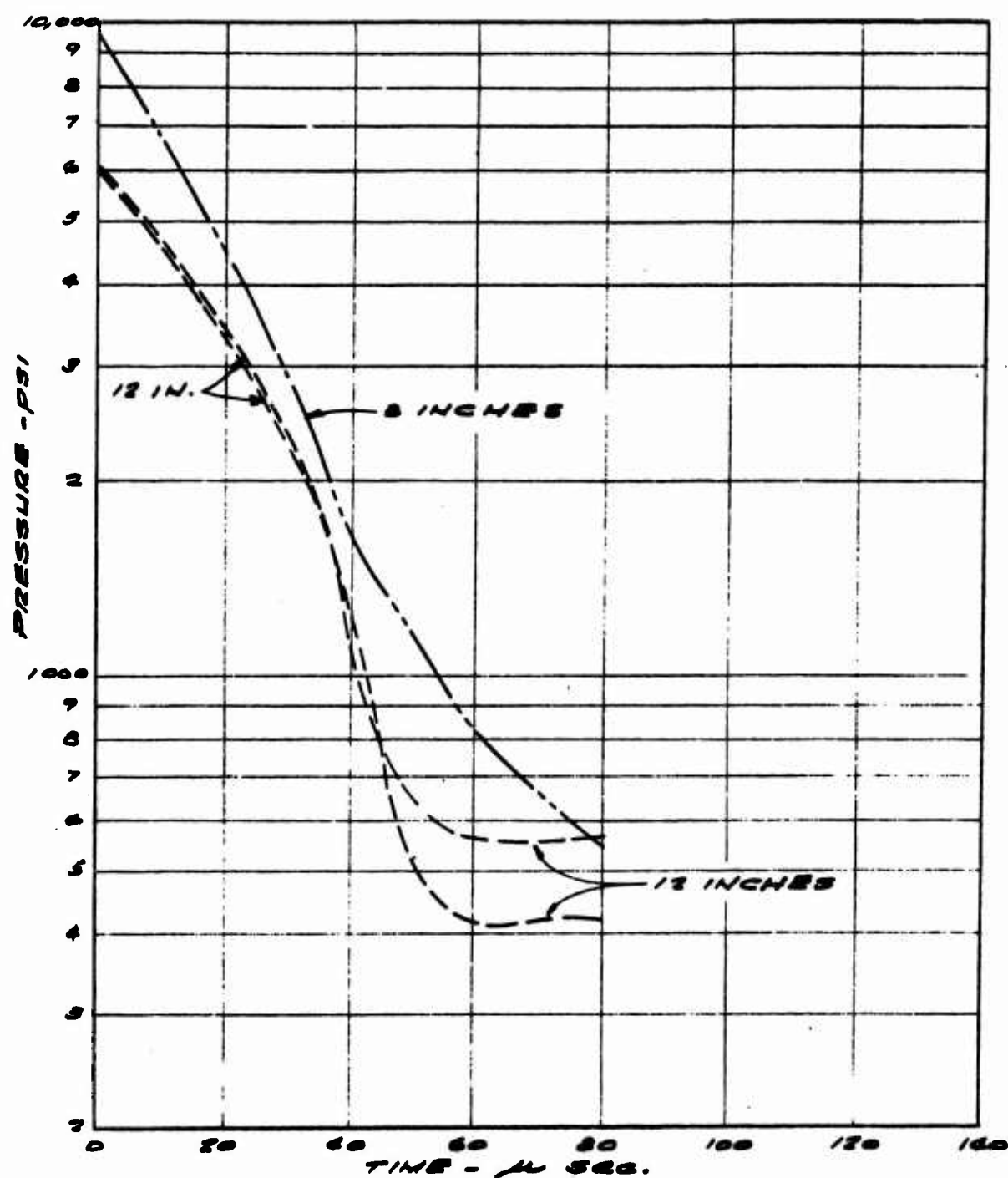


FIGURE 24A. PRESSURE VS TIME, FOR 14.8 GM PENTOLITE
CHARGE DETONATED UNDER 3000 PSI
HYDROSTATIC PRESSURE

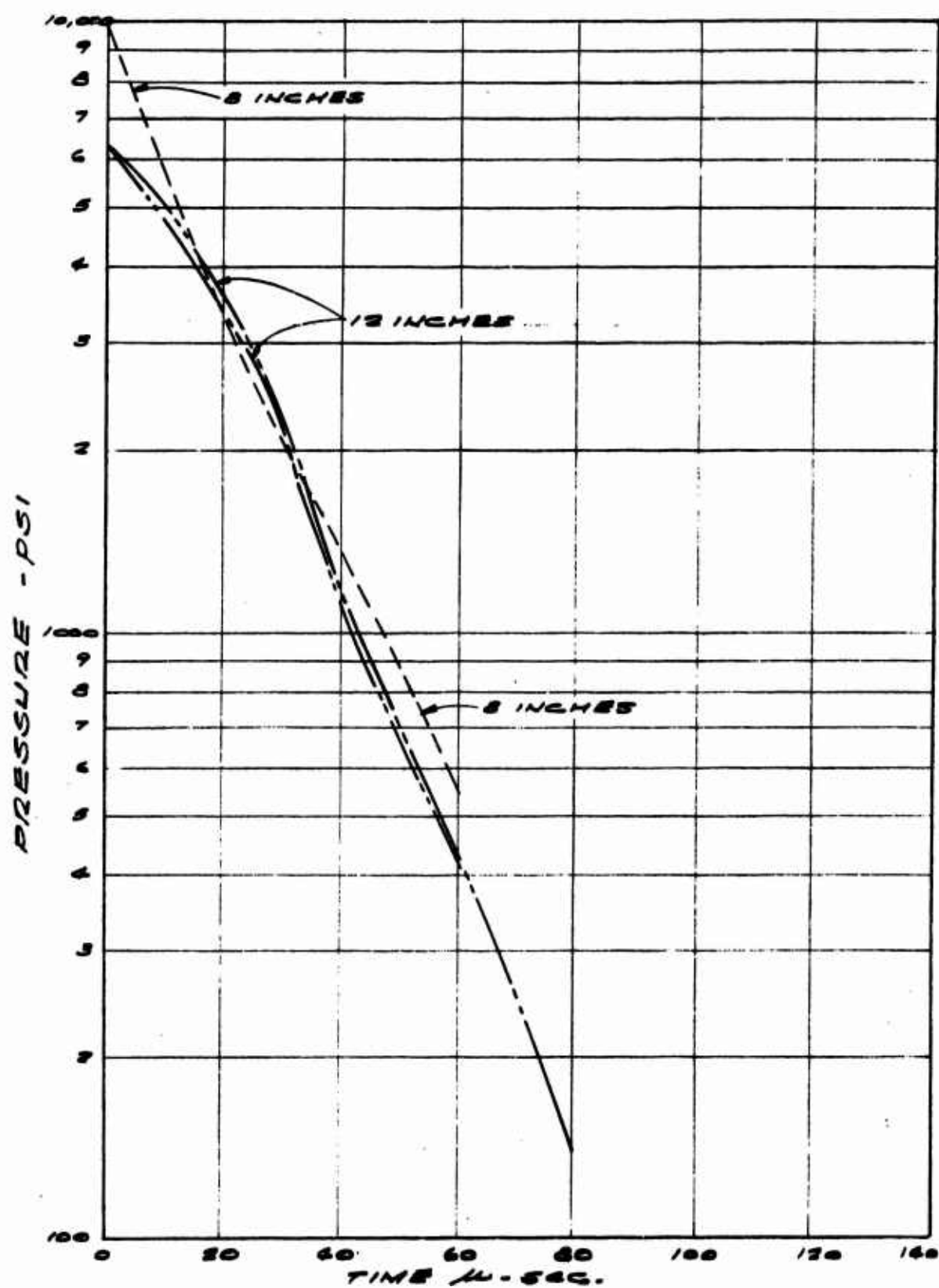


FIGURE 25A. PRESSURE VS TIME, FOR 14.7 GM PENTOLITE
CHARGE DETONATED UNDER 3500 PSI
HYDROSTATIC PRESSURE

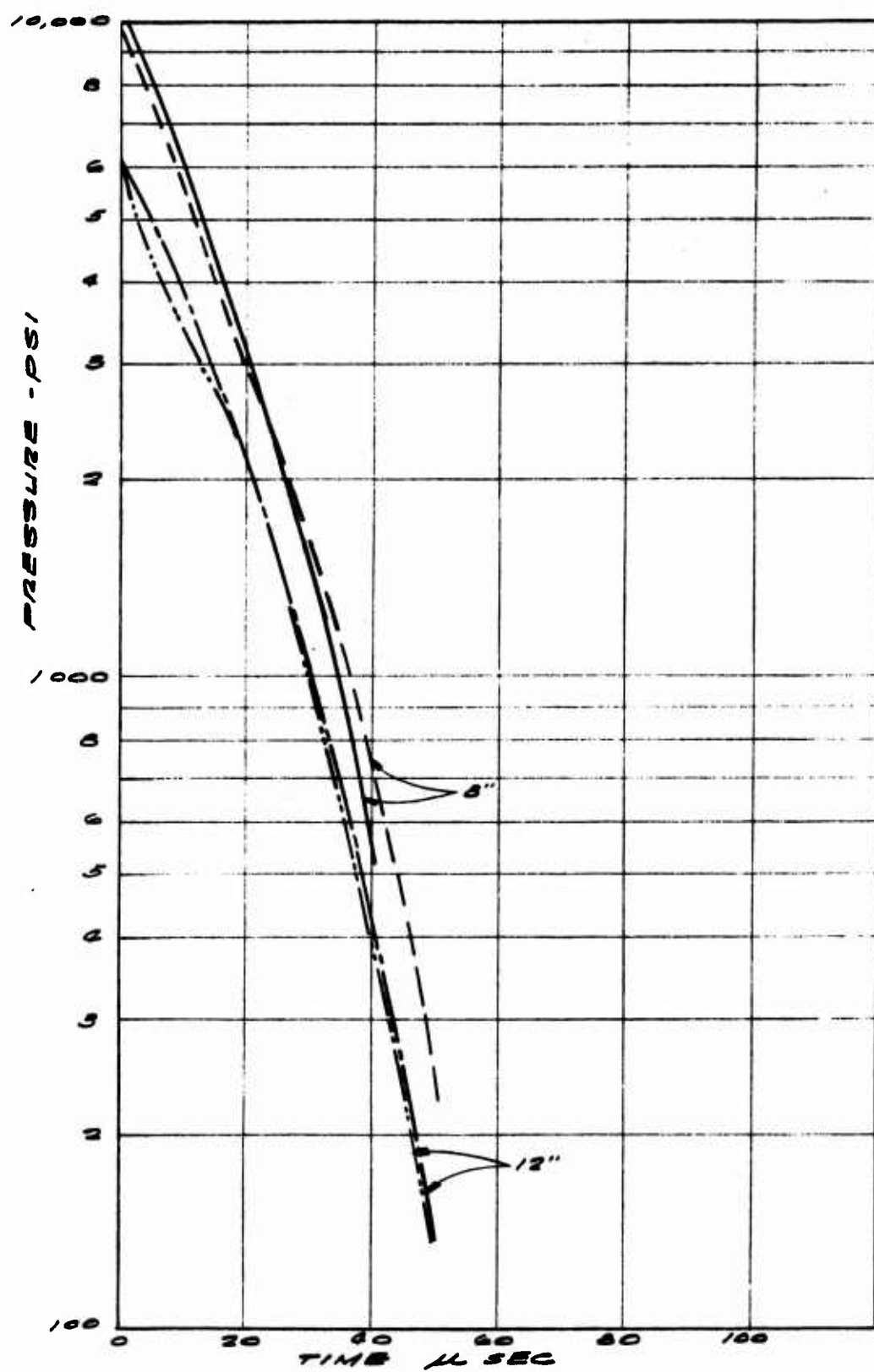
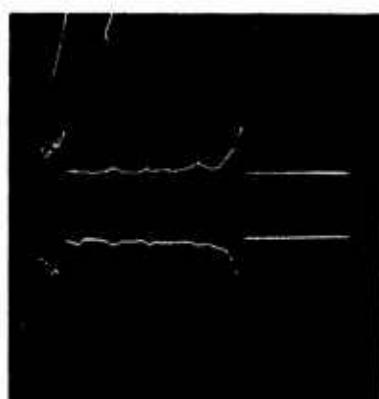


FIGURE 26A. PRESSURE VERSUS TIME FOR 14.7-GM PENTOLITE CHARGE DETONATED UNDER 4000 PSI HYDROSTATIC PRESSURE

APPENDIX B

OSCILLOSCOPE RECORDS OF TESTS WITH 7.4-GM PENTOLITE CHARGES

Note: The suspension frame shown in Figure 5 was used for all tests noted in Appendix B. The two top gages were 12 inches from the charge center and the bottom gages were at a distance of 8 inches.



50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



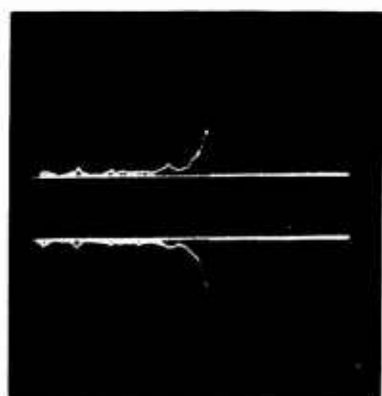
50 $\mu\text{sec/cm}$, 0.5 v/cm
Bottom Gauges

Comments: Bubble pulse shown in Figure 2C.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	1.65	1.5	2.6	2.9
Measured press., psi	4520	4550	6950	7130
Calc. press., psi	5050	5050	7950	7950
Area, cm^2	0.811	0.75	1.00	1.13
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.110	0.109	0.134	0.139
Duration, μsec	155	150	120	130
Negative press., psi	-	-	-	-

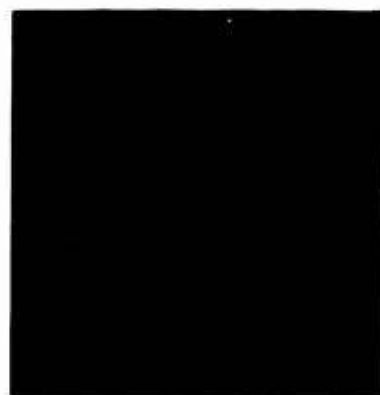
Figure 1B, Shot 1B, Zero psi



7

9

50 $\mu\text{sec/cm}$, 0.5 v/cm
Top Gauges



8

3

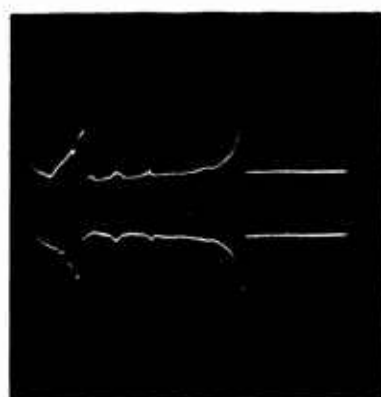
50 $\mu\text{sec/cm}$, 0.5 v/cm
Bottom Gauges

Comments: Bubble pulse shown in Figure 3C.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	1.65	1.45	3.0	3.1
Measured press., psi	4360	4230	8010	7610
Calc. press., psi	5050	5050	7950	7950
Area, cm^2	0.875	0.75	1.06	1.13
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.119	0.110	0.142	0.139
Duration, μsec	153	150	130	130
Negative press., psi	-	-	-	-

Figure 2B, Shot 2B, Zero psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



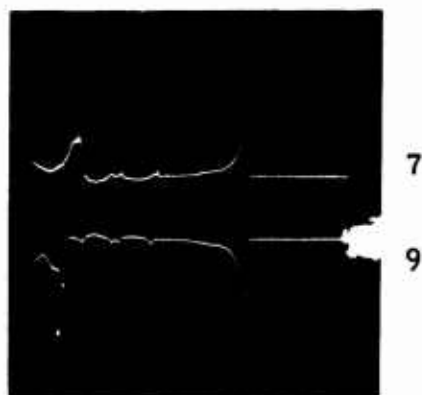
50 μ sec/cm, 0.5 v/cm
Bottom Gauges

Comments: No bubble pulse

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	1.8	1.65	3.0	3.0
Measured press., psi	4900	4800	8010	7370
Calc. press., psi	5050	5050	7950	7950
Area, cm ²	0.625	0.564	0.875	0.875
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.085	0.0825	0.118	0.108
Duration, μ sec	105	115	105	95
Negative press., psi	~270	~290	~400	~420

Figure 3B, Shot 3B, 2000 psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



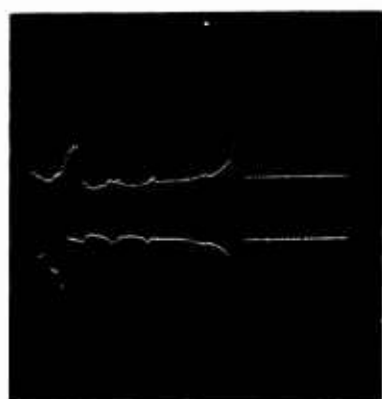
50 μ sec/cm, 0.5 v/cm
Bottom Gauges

Comments: Bubble pulse shown in Figure 4C.

Charge Weight: 7.45 gms Pentolite + J-2 cap = 8.55 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	1.85	1.7	3.0	3.05
Measured press., psi	5010	4960	8010	7450
Calc. press., psi	5050	5050	7950	7950
Area, cm ²	0.75	0.687	1.00	1.06
Unit impulse, $\frac{\# \text{sec}}{\text{in}^2}$	0.102	0.10	0.134	0.130
Duration, μ sec	120	115	110	105
Negative press., psi	~135	~145	~265	~245

Figure 4B, Shot 4B, 1500 psi



50 μ sec/cm, 0.5 v/cm
Top Gauges



50 μ sec/cm, 0.5 v/cm
Bottom Gauges

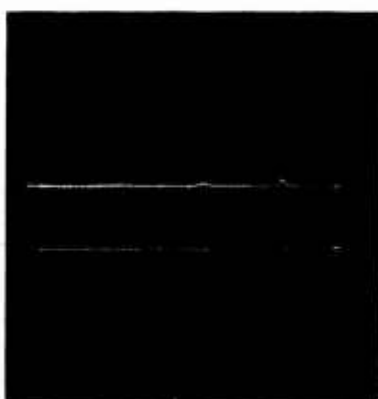
Comments: Bubble pulse shown in Figure 5C.

Charge Weight: 7.45 gms Pentolite + J-2 cap = 8.55 gms

	<u>Top Gauges</u>		<u>Bottom Gauges</u>	
	<u>7</u>	<u>9</u>	<u>8</u>	<u>3</u>
Distance, in.	12	12	8	8
Deflection, cm.	1.85	1.65	3.0	3.0
Measured press., psi	5010	4800	8010	7370
Calc. press., psi	5050	5050	7950	7950
Area, cm ²	0.5	0.5	0.875	0.813
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	.067	.073	0.117	0.100
Duration, μ sec	83	85	78	75
Negative press., psi	~545	~580	~800	~860

Figure 5B, Shot 5B, 3000 psi

APPENDIX C
OSCILLOSCOPE RECORDS OF
BUBBLE PULSE DATA



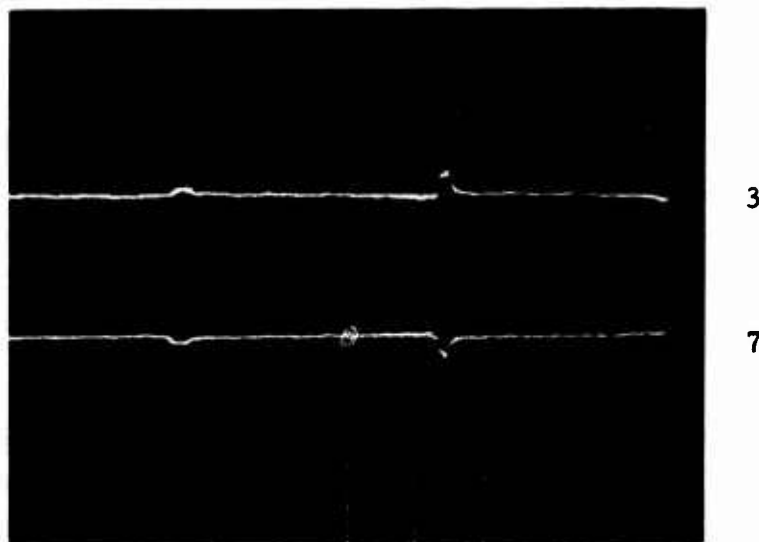
20 msec/cm, 0.2 v/cm
Bottom Gauges

Comments: Bubble pulse measurement only

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Bottom Gauges</u>	
	<u>8</u>	<u>3</u>
Distance, in.	8	8
Deflection, cm.	0.25	0.25
Measured press., psi	~265	~245
First period, msec	40	40
Second period, msec	54	54

Figure 1C, Shot 1A, Zero psi, Bubble Pulse



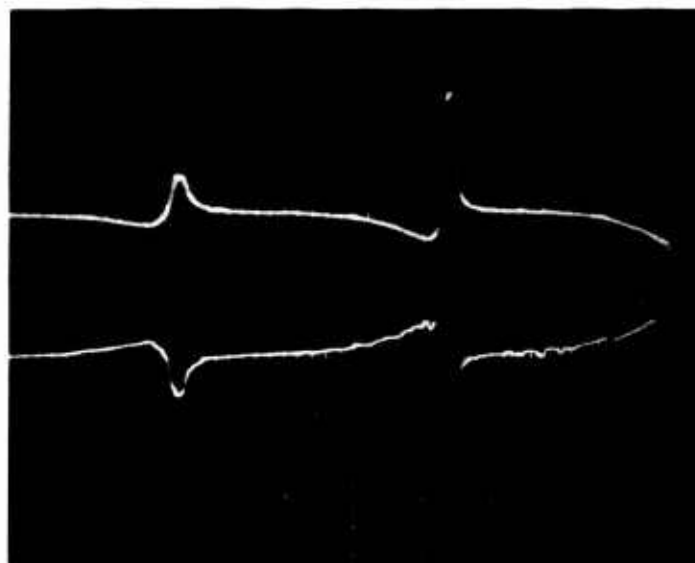
.02 sec/cm, .05 v/cm

Comments: Values below are considered approximate. See Figure 1B for shock pressures.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauge</u>	<u>Bottom Gauge</u>
	<u>7</u>	<u>3</u>
Distance, in.	12	8
Deflection, cm.	~0.28	0.3
Measured press., psi	76	74
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.314	0.338
Duration, msec	7.6	7.0
Calc. period, msec	57	57
Measured period, 1st pulse, msec	64	65
Measured period, 2nd pulse, msec	77	76

Figure 2C, Shot 1B, Zero psi, Bubble Pulse



.02 sec/cm, .02 v/cm

Comments: See Figure 2B for shock pressures.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauge</u>	<u>Bottom Gauge</u>
	<u>7</u>	<u>3</u>
Distance, in.	12	8
Deflection, cm.	1.9	1.63
Measured press., psi	208	160
Deflection, peak to peak, cm.	2.5	2.1
Δ press., peak to peak, psi	270	206
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.780	0.850
Duration, msec	9.0	8.6
Calc. period, msec	57	57
Measured period, 1st pulse, msec	69	72
Measured period, 2nd pulse, msec	78	78

Figure 3C, Shot 2B, Zero psi, Bubble Pulse



3

7

0.002 sec/cm, .05 v/cm

Comments: Values below are considered approximate. See Figure 4B for shock pressures.

Charge Weight: 7.45 gms Pentolite + J-2 cap = 8.55 gms

	<u>Top Gauge</u>	<u>Bottom Gauge</u>
	<u>7</u>	<u>3</u>
Distance, in.	12	8
Deflection, peak to peak, cm.	518	541
Δ press., psi	-	-
Unit impulse, $\frac{\# \text{ sec}}{\text{in}^2}$	0.107	.079
Measured period, msec	1.5	1.6
Calculated period, msec	1.3	1.3

Figure 4C, Shot 4B, 1500 psi, Bubble Pulse



3

7

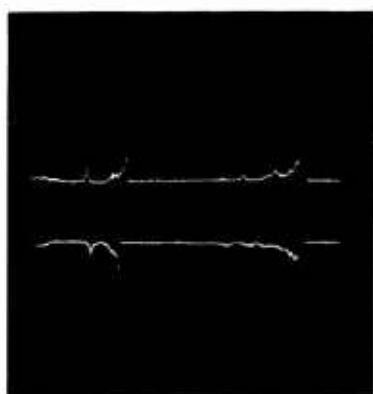
0.001 sec/cm, 0.1 v/cm

Comments: Values below are considered approximate.

Charge Weight: 7.45 gms Pentolite + J-2 cap = 8.55 gms

	<u>Top Gauge</u>	<u>Bottom Gauge</u>
	<u>7</u>	<u>3</u>
Distance, in.	-	-
Deflection, peak to peak, cm.	2	2
Δ press., psi	1090	980
Measured period, msec	0.7	0.7
Calculated period, msec	0.735	0.735

Figure 5C, Shot 5B, 3000 psi, Bubble Pulse



533

536

100 μ sec/cm, 0.5 v/cm
Top Gauges



536

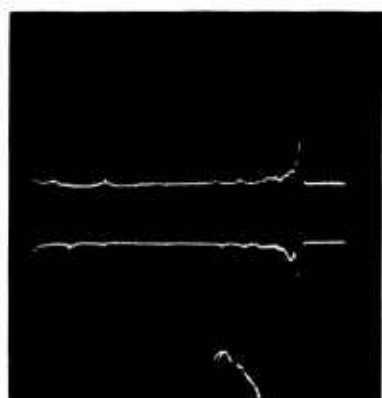
20 msec/cm, .02 v/cm
Bubble Pulse

Comments: Four-foot diameter tank

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauges</u>		<u>Bubble Pulse</u>
	<u>533</u>	<u>536</u>	<u>536</u>
Distance, in.	8	8	8
Deflection, cm.	3.2	>3.0	4.3 pk to pk
Measured press., psi	9020	>8090	465
Calc. press., psi	7950	7950	-
Calculated period, msec	-	-	57
Measured period, msec	-	-	54

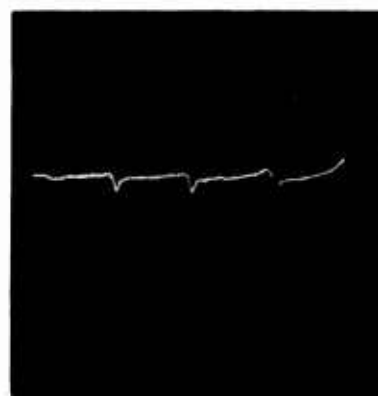
Figure 6C, Shot 6B, Zero psi, Bubble Pulse



533

536

100 μ sec/cm, 0.5 v/cm
Top Gauges



536

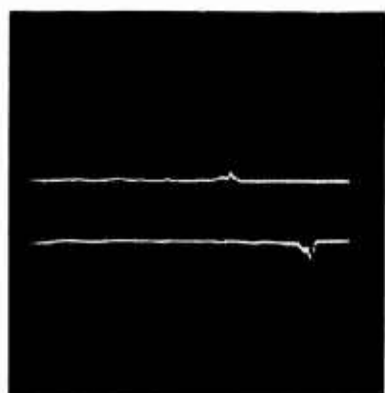
20 msec/cm, .02 v/cm
Bubble Pulse

Comments: Four-foot diameter tank

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Top Gauges</u>		<u>Bubble Pulse</u>
	<u>533</u>	<u>536</u>	<u>536</u>
Distance, in.	8	8	8
Deflection, cm.	>3.4	>3.0	2.7 pk to pk
Measured press., psi	>9580	>8050	290
Calc. press., psi	7950	7950	-
Calculated period, msec	-	-	57
Measured period, msec	-	-	56

Figure 7C, Shot 7B, Zero psi, Bubble Pulse



533

536

100 μ sec/cm, 1.0 v/cm
Top and Outside Gauges



536

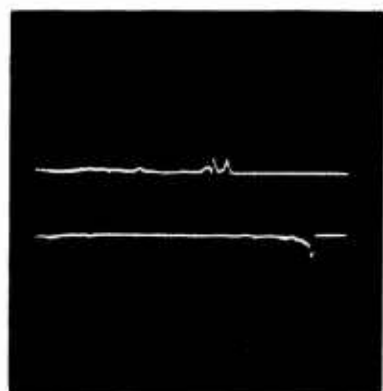
20 msec/cm, .02 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 533 outside of wire mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

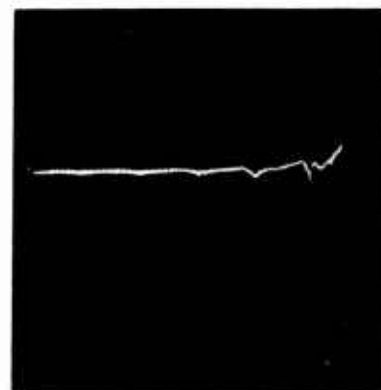
	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>533</u>	<u>536</u>	<u>536</u>
Distance, in.	~24	8	8
Deflection, cm.	0.3	1.75	1.3 pk to pk
Measured press., psi	1690	9400	140
Calc. press., psi	2280	7950	-
Calculated period, msec	-	-	57
Measured period, msec	-	-	42

Figure 8C, Shot 8B, Zero psi, Bubble Pulse



534

536



536

100 μ sec/cm, 0.5 v/cm (534), 1.0 v/cm (536)
Top and Outside Gauges

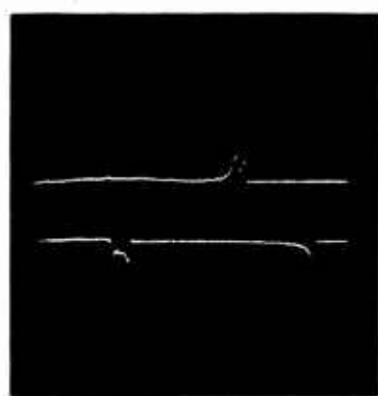
20 msec/cm, .02 v/cm
Bubble Pulse

Comments: Four-foot diameter vessel. Vessel shielded by wire mesh.
Gage 534 outside of wire mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	~24	8	8
Deflection, cm.	0.6	1.8	1.4 pk to pk
Measured press., psi	1680	9680	150
Calc. press., psi	2280	7950	-
Calculated period, msec	-	-	57
Measured period, msec	-	-	38

Figure 9C, Shot 9B, Zero psi, Bubble Pulse



534

536

100 μ sec/cm, 0.5 v/cm (534), 1.0 v/cm (536)
Top and Outside Gauges



536

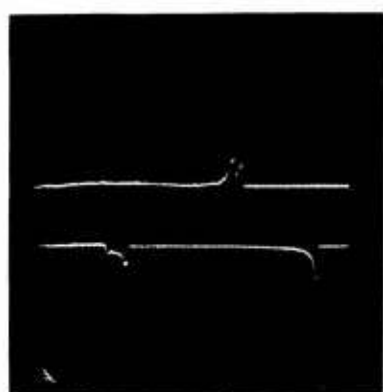
2.0 msec/cm, .02 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 534 outside mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	~24	8	8
Deflection, cm.	0.7	1.35	6.0 pk to pk
Measured press., psi	1970	7250	640
Calc. press., psi	2280	7950	-
Calculated period, msec	-	-	3.26
Measured period, msec	-	-	3.4

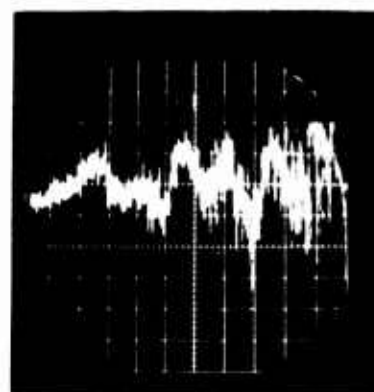
Figure 10C, Shot 10B, 500 psi, Bubble Pulse



534

536

100 μ sec/cm, 0.5 v/cm (534), 1.0 v/cm (536)
Top and Outside Gauges



536

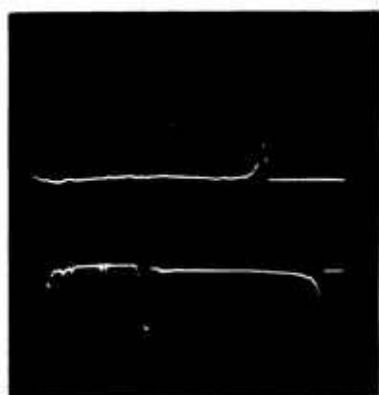
2.0 msec/cm, .05 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 534 outside wire mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	24	12	12
Deflection, cm.	1.0	1.5	3.3
Measured press., psi	2810	8050	890
Calc. press., psi	2280	7950	-
Calculated period, msec	-	-	3.26
Measured period, msec	-	-	3.4

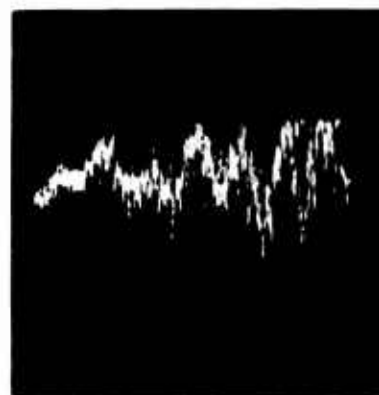
Figure 11C, Shot 11B, 500 psi, Bubble Pulse



534

536

100 μ sec/cm, 0.5 v/cm
Top and Outside Gauges



536

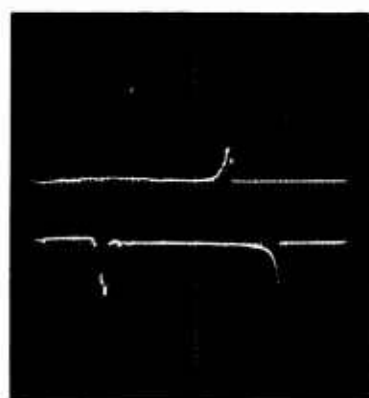
2.0 msec/cm, .05 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 534 outside mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	24	12	12
Deflection, cm.	1.2	-	3.7 pk to pk
Measured press., psi	3372	-	995
Calc. press., psi	2280	5050	-
Calculated period, msec	-	-	3.26
Measured period, msec	-	-	~3.0

Figure 12C, Shot 12B, 500 psi, Bubble Pulse



100 μ sec/cm, 0.5 v/cm
Top and Outside Gauges



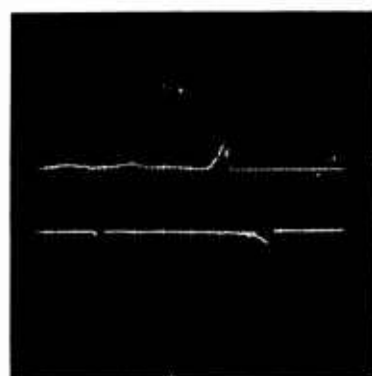
5.0 msec/cm, .05 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 534 outside mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	24	15	15
Deflection, cm.	1.0	1.3	3.4 pk to pk
Measured press., psi	2810	3500	915
Calc. press., psi	2280	3920	-
Calculated period, msec	-	-	3.26
Measured period, msec	-	-	~3.0

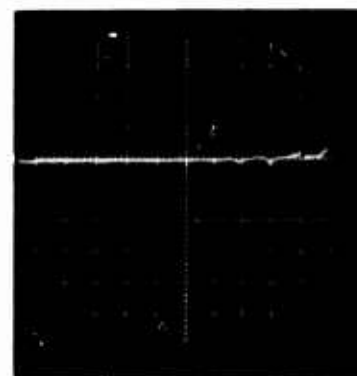
Figure 13C, Shot 13B, 500 psi, Bubble Pulse



534

536

100 sec/cm, 0.5 v/cm
Top and Outside Gauges



536

20 msec/cm, .05 v/cm
Bubble Pulse

Comments: Four-foot diameter tank. Vessel shielded by wire mesh.
Gauge 534 outside mesh.

Charge Weight: 7.4 gms Pentolite + J-2 cap = 8.5 gms

	<u>Outside Gauge</u>	<u>Top Gauge</u>	<u>Bubble Pulse</u>
	<u>534</u>	<u>536</u>	<u>536</u>
Distance, in.	24	15	15
Deflection, cm.	0.9	1.3	0.9
Measured press., psi	2530	3500	240
Calc. press., psi	2280	3920	-
Calculated period, msec	-	-	29
Measured period, msec	-	-	~24

Figure 14C, Shot 14B, 20 psi, Bubble Pulse

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		2b. GROUP
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Field Projects Branch, Earth Sciences Div. Office of Naval Research Washington 25, D.C.	
13. ABSTRACT Underwater explosions at great depth have been simulated by detonating small spherical pentolite charges in vessels hydrostatically pressured to 4000 psi. An increase in hydrostatic pressure is found to have no effect on the peak magnitude of the primary shock wave, but the impulse per unit area and the duration of the positive phase of the initial pressure pulse are observed to decrease with an increase in hydrostatic pressure. The magnitude of the negative phase of the shock wave increases as the hydrostatic pressure increases. Although little difficulty is encountered in studying primary pressure pulses in pressure vessels, secondary pressure pulses created by expansion and contraction of the gas bubble formed by the detonation are difficult to observe due to the large displacement of the water particles at close-in distances and the associated acceleration of the piezoelectric pressure transducer at the times of interest. Also, the myriad of reflections from the gauge positioning devices and the vessel walls and the inconsistency usually exhibited by bubble pulses under seemingly identical conditions complicate analysis of the secondary pulses. The magnitude of the bubble pulse appears to increase as the hydrostatic pressure increases, and, at moderately high hydrostatic levels, the frequency of the bubble oscillation is such that the bubble pulse is recorded as a vibration. (U)		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Underwater Explosions, Effect of Depth Upon						

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